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Impact of Artificial Intelligence in the Pharmaceutical Business:
A Bibliometric Analysis

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June, 2024

Department of Strategy, Marketing, Operations and General Management

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Acknowledgments

To Júlia and Isabel, for being the light of my life.

To my parents, sister, and nephews, for being my family in this life journey.

To my professors, for your time and dedication showing me the right paths.

Thank you.

Resumo

Esta tese examina sistematicamente o impacto da inteligência artificial (IA) no setor farmacêutico através de uma meticulosa análise bibliométrica utilizando Elsevier Scopus e Vos viewer. A pesquisa revela um notável aumento nas publicações académicas, reflexo de um crescente interesse académico na convergência entre Inteligência Artificial e o setor farmacêutico. Por meio de uma síntese abrangente da literatura existente, o estudo fornece recomendações práticas e insights valiosos para pesquisadores e partes interessadas. Ao delinear tendências chave, artigos influentes e temas emergentes, esta pesquisa serve como um guia para navegar na paisagem intricada da interseção transformadora entre IA e farmacêutica. Os resultados contribuem para uma compreensão matizada do impacto atual da IA e oferecem antecipação das suas possíveis implicações dentro deste dinâmico domínio empresarial.

Palavras-chave: Inteligência Artificial, Negócio Farmacêutico, Análise Bibliométrica, Sector Farmacêutico, Tendências, Recomendações, Impacto Académico

Classificação JEL:

L22- Firm Organization and Market Structure

O32 – Management of Technological Innovation and R&D

Abstract

This thesis systematically examines the impact of artificial intelligence (AI) on the pharmaceutical business through a meticulous bibliometric analysis utilizing Elsevier Scopus and Vos viewer. The research uncovers a notable upswing in academic publications, reflective of an expanding scholarly interest in the convergence of Artificial Intelligence and the pharmaceutical sector. Through a comprehensive synthesis of existing literature, the study provides practical recommendations and valuable insights for researchers and stakeholders. By delineating key trends, influential articles, and emerging themes, this research serves as a guide for navigating the intricate landscape of the transformative intersection between AI and pharmaceuticals. The findings contribute to a nuanced understanding of the current impact of AI and offer anticipation of its prospective implications within this dynamic business domain.

Keywords: Artificial Intelligence, Pharmaceutical Business, Bibliometric Analysis, Pharmaceutical Sector, Trends, Recommendations, Scholarly Impact

JEL Classification:

L22- Firm Organization and Market Structure

O32 – Management of Technological Innovation and R&D

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CHAPTER 1

Introduction

The advent of Artificial Intelligence (AI) brought a paradigm shift across the healthcare industry, revolutionizing the way processes are executed, decisions are made, and innovation is fostered (Jiang et al., 2017). The pharmaceutical sector, a vital component of the global healthcare business, has not remained untouched by this transformative wave. The integration of AI in pharmaceutical practices has shown promising potential to enhance drug discovery, optimize clinical trials, personalize healthcare, and improve overall operational efficiency (Zhavoronkov, 2019). Presently, advancements in pharmaceutical manufacturing technologies are ongoing, with the emergence of the internet of things, artificial intelligence, robotics, and advanced computing. These innovations are starting to disrupt conventional methods, practices, and business models in the pharmaceutical manufacturing industry (Arden et al, 2021).

AI's potential to transform processes such as disease diagnosis, drug discovery, and clinical trial optimization has garnered attention. AI-enabled pharmaceutical technologies are poised to shape the future of healthcare, offering opportunities to enhance efficiency and reduce costs (Bhattamisra et al, 2023). The integration of artificial intelligence (AI) into the pharmaceutical industry has the potential to transform drug development processes significantly. Machine learning and deep learning methods enable thorough analysis of chemical structures and activity relationships in pharmaceutical data, enhancing drug discovery efforts. Despite challenges such as managing large datasets and optimizing deep learning models, AI-based tools are increasingly essential in computer-assisted drug development, particularly in de novo design and lead molecule identification (Selvaraj et al, 2022).

The increasing data-driven demands combined with scientific decision-making that govern modern pharma make the industry a strong candidate for the application of AI technologies. With internal investment in data integration and AI talent, pharma companies can overcome the challenges (Henstock, 2019). Understanding the precise impact and trends of AI integration in the pharmaceutical business is essential, thus prompting the focus of this bibliometric analysis.

The focal point of inquiry in this study lies in the transformative influence exerted by artificial intelligence (AI) within the pharmaceutical sector. Through a bibliometric analysis, the study seeks to uncover trends, challenges, and opportunities in AI adoption within the pharmaceutical industry. By examining existing literature, the research endeavors to provide valuable insights into the current state of AI-driven advancements, shedding light on both theoretical and practical implications. Additionally, the study may address the complexities and limitations associated with the implementation of AI technologies in pharmaceutical practices, ultimately contributing to a deeper understanding of this rapidly evolving field. The formulated research questions, ranging from discerning overall publication trends to analyzing the clustering of keywords, aim to provide comprehensive insights into the dynamics and implications of AI integration in the pharmaceutical landscape, thus enriching the overarching comprehension of this transformative phenomenon.

The first chapter of this dissertation serves as an introduction to the subject matter, elucidating the study's goals and delineating its objectives. Additionally, it outlines the general framework of the dissertation while offering a concise preview of the influence of artificial intelligence on the pharmaceutical business.

The second chapter, dedicated to the methodology, introduces the research questions that will shape the investigation. It delineates the chosen approach, that consists in a bibliometric analysis. Furthermore, it elucidates the process of article selection and outlines the criteria governing the research. The research goals are subsequently outlined, accompanied by an overview of the PRISMA methodology.

Chapter three delves into the bibliometric analysis, highlighting outcomes derived from Elsevier Scopus and revealing correlations identified through the utilization of the Vos viewer. Through a thorough examination of existing literature, this chapter offers valuable perspectives on the present status of research concerning the impact of Artificial Intelligence in the pharmaceutical business.

Chapter four is dedicated to the discussion and exploration of research findings. Structured around the research questions, this chapter facilitates a detailed analysis of the key insights gleaned from the reviewed papers. It aims to enhance comprehension of the topic by delving into significant findings uncovered through this comprehensive review.

Chapter five functions as the conclusive segment of the dissertation, encapsulating the pivotal discoveries gleaned from the research. It furnishes a succinct response to the primary research query, elucidating both the theoretical and practical merits derived from the study. Furthermore, this chapter proffers suggestions for prospective research endeavors and delineates potential domains warranting deeper exploration. Additionally, it delves into the constraints confronted throughout the thesis development. By recognizing these limitations, the thesis establishes a framework within which the research findings ought to be construed, thereby enriching the overarching comprehension of the subject matter.

CHAPTER 2

Methodology

2.1 Research questions:

This study aims to explore the Impact of Artificial Intelligence in the Pharmaceutical Business. The research questions for this study are as follows:

Q1: What is the overall trend in academic publications related to the impact of artificial intelligence (AI) in the pharmaceutical business between 2019 and 2023?

Q2: What are the most cited and influential research articles in the domain of AI's impact on the pharmaceutical business?

Q3: How does the co-occurrence and clustering of keywords in academic literature reflect the evolving landscape of Artificial Intelligence applications in the pharmaceutical business, and what insights can be gained from the analysis of key clusters and their associated themes?

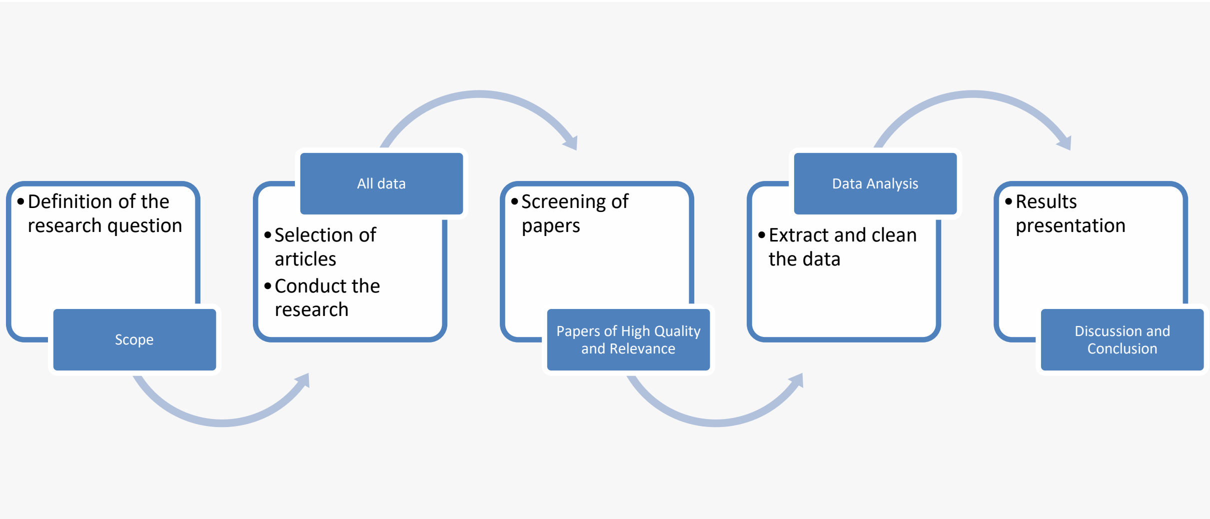
2.2 Identification of the research

This study will follow the bibliometric analysis guidelines as outlined by Professor Doctor Leandro F. Pereira in the Bibliometric State-of-the-Art Research Checklist.

Bibliometrics plays a vital role in evaluating and studying multiple facets of the scientific domain, including researchers productivity, university collaborations, the influence of state-funded science initiatives on national research and development, and educational effectiveness (Moral-Muñoz et al., 2020). Bibliometric analysis has witnessed a notable surge in popularity within the realm of business research in recent times. This growing interest can be attributed to a couple of key factors. First and foremost, it's the advancement and wide accessibility of specialized bibliometric software like Gephi, Leximancer, VOSviewer, coupled with the abundance of comprehensive scientific databases such as Scopus and Web of Science. Secondly, there's been a significant cross-disciplinary influence, with bibliometric methodology migrating from information science to find a valuable place within the domain of business research (Donthu et al., 2021).

The literature review process involves three primary stages: planning, conducting, and reporting. In the planning stage, researchers identify the need for the review, formulate research questions, and develop a review protocol. The next steps encompass formulating the research problem, validating the review protocol, conducting a comprehensive literature search, screening for inclusion, assessing the quality of selected studies, extracting relevant data, analyzing and synthesizing the data, and finally, reporting the findings. It is crucial to note that the process is iterative, allowing for modifications to the research question or protocol when unforeseen issues arise during the review (Xiao & Watson, 2019). In the systematic literature review process outlined by Linnenluecke, Marrone, and Singh (2020), there are four key steps. Firstly, one must identify pertinent literature to be included. Following that, the selected studies undergo a process of cleaning and screening to ensure quality and relevance. The next step involves the analysis and synthesis of data extracted from the chosen studies. Lastly, the results of this analysis are presented in a clear and concise manner. Based on these two approaches, the study will adopt the research methodology illustrated in Figure 1.

Figure 1 – Research Method Scheme



Source: Self-elaborated

2.3 Articles selection

The article selection process will commence with a search in Elsevier Scopus, enabling the retrieval of a larger sample of documents through the application of suitable filters and keywords. This method will assist in identifying literature that could be pertinent to the research proposal. Following an initial screening of articles based on their abstracts, subsequently followed by a thorough review of the full texts, the initial sample will start to decrease. This approach will be adopted to ensure the selection of the most significant and high-quality articles.

2.4 Data criteria

The articles were searched in February 28 2024, including the follow criteria:

1) Elsevier Scopus as a database to search;
2) Search terms of Artificial Intelligence and Pharmaceutical;
3) Only articles that were published in the period between January 1 2019 and December 31 2023, covering a five years analysis period;

For Screening of documents were added the following filters:

4) English language academic articles, reviews, conference papers and book chapters;
5) The research conducted was limited to the areas of *Pharmacology, Toxicology and Pharmaceutics, Computer Science, Econometrics and Finance and Business Management and Consulting*

2.5 Research objectives

To answer the research questions, research objectives were defined to better outline the research.

Research Question 1

(Q1): What is the overall trend in academic publications related to the impact of artificial intelligence (AI) in the pharmaceutical business between 2019 and 2023?

Corresponding Research Objectives:

1) Conduct a systematic literature review to identify and collect academic publications related to AI's impact on the pharmaceutical business from 2019 to 2023.
2) Analyse and quantify the annual publication trends and patterns in academic articles regarding AI in the pharmaceutical business during the specified timeframe.
3) Investigate the distribution of publications across different publication sources (journals, conferences, etc.) to identify prominent platforms for AI-related research in the pharmaceutical domain.
4) Assess the geographical distribution of research output to identify regions with significant contributions to the field of AI in pharmaceuticals.

Research Question 2

(Q2): What are the most cited and influential research articles in the domain of AI's impact on the pharmaceutical business?

Corresponding Research Objectives:

1) Compile a comprehensive database of academic articles related to AI in the pharmaceutical business and their corresponding citation counts.
2) Identify the most cited and influential research articles within this domain during the specified period.
3) Analyse the characteristics and themes of the most cited articles to understand the factors contributing to their influence and impact.
4) Investigate the citation network and identify clusters of highly influential research articles, indicating key research directions and seminal works.

Research Question 3

(Q3): How does the co-occurrence and clustering of keywords in academic literature reflect the evolving landscape of Artificial Intelligence applications in the pharmaceutical business, and what insights can be gained from the analysis of key clusters and their associated themes?

Corresponding Research Objectives:

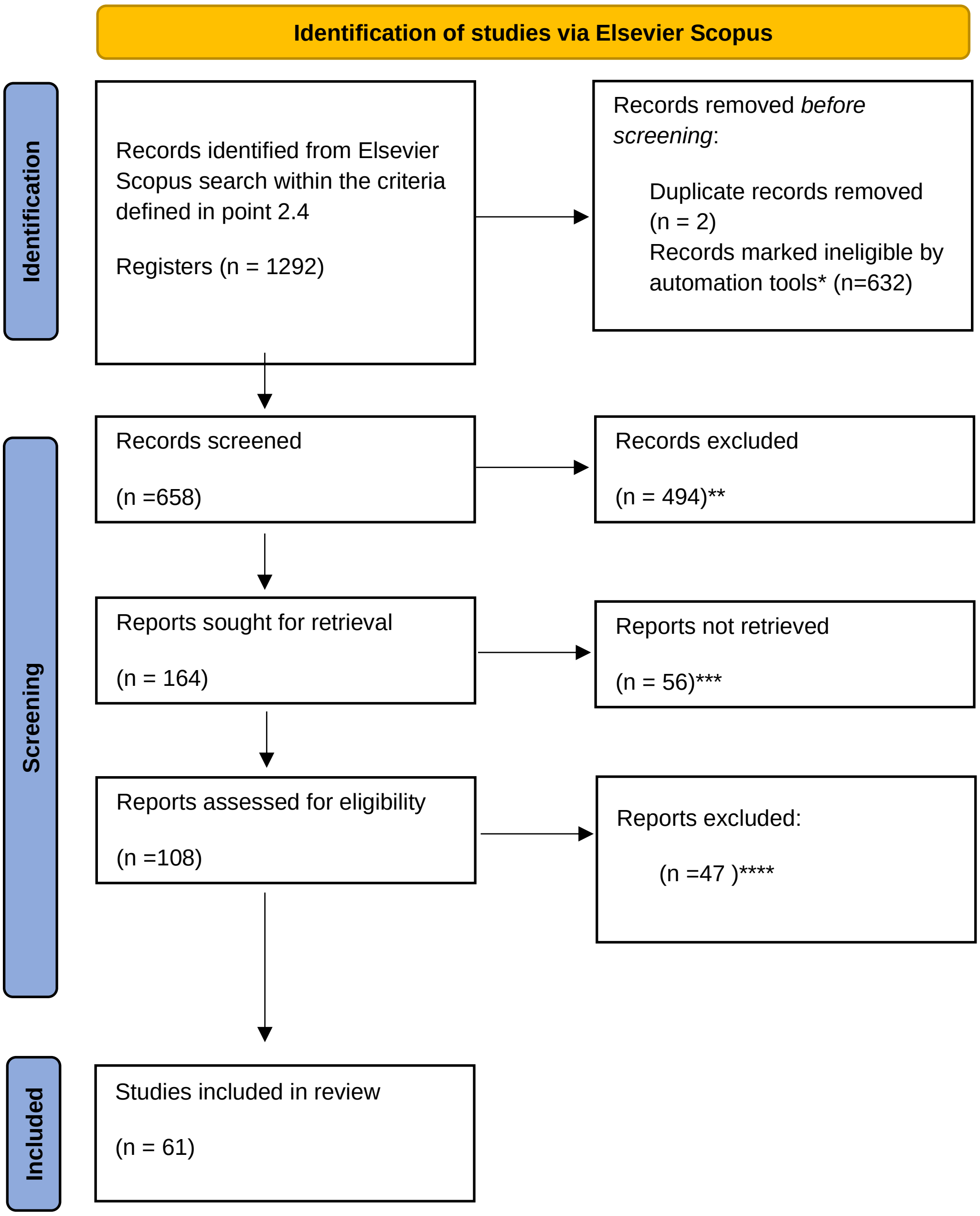
1) Investigate the co-occurrence patterns of keywords within the intersection of Artificial Intelligence and pharmaceutical business literature.
2) Examine the results of the VOS viewer keyword clustering, which grouped keywords into distinct clusters.
3) Conduct a detailed analysis of the selected keywords from the articles in Annex A.
   Identify emerging research themes and advancements within each subtopic, considering both keyword co-occurrence and content analysis.

2.6 Articles screening

The articles were screened by PRISMA Methodology. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology serves as a comprehensive guideline for conducting and reporting systematic reviews and meta-analyses in various fields, including bibliometric analysis. Moher et al. (2009) initially introduced the PRISMA Statement, providing a structured framework for researchers to ensure transparency and completeness in reporting their findings. Liberati et al. (2009) provided an explanatory document for the PRISMA statement, offering detailed elaboration and clarification on each reporting item. The PRISMA 2020 update, as outlined by Page et al. (2021), further refines and enhances the reporting standards, offering updated guidance for systematic review authors, editors, and peer reviewers. The PRISMA methodology comprises several key steps, including planning, literature search, study selection, data extraction, quality assessment, data synthesis, results reporting, and discussion and conclusion.

The articles were subjected to screening following the PRISMA Methodology (Page et al., 2021), wherein a search was conducted on February 28, 2024, utilizing Elsevier Scopus as the database, focusing on articles published between January 1, 2019, and December 31, 2023, resulting in 1,292 records identified through the search terms "Artificial Intelligence" and "Pharmaceutical". Subsequently, the screening process was refined by applying filters, including English language academic articles, reviews, conference papers, and book chapters, and restricting the research to areas of Pharmacology, Toxicology and Pharmaceutics, Computer Science, Econometrics and Finance, and Business Management and Consulting. After removing duplicates, 658 documents remained, of which 494 were excluded due to low citation counts. This led to 164 reports sought for retrieval, with 56 further records excluded due to the absence of full text available. Ultimately, 108 reports were assessed for eligibility, with 47 excluded for being highly specific studies unrelated to the broader impact on the pharmaceutical business, resulting in 61 studies included in the final review.

Figure 2 – PRISMA Methodology



*Used filter of Elsevier Scopus of limit language to English; Subjects Area of Pharmacology, Toxicology and Pharmaceutics, Computer Science, Business Management and Accounting and Economics, Econometrics and Finance ; document type of Article, Review, Conference Paper and Book Chapter resulting in 658 documents found (after removal of 2 duplicated)

**Excluded due to have <10 citations

*** Excluded due to the absence of full text available

**** Excluded because they are highly specific studies related to some innovative therapy or specific innovative method not likely to impact the pharmaceutical business as a whole

CHAPTER 3

Bibliometric Analysis

3.1 Overall findings

3.1.1 Elsevier Scopus

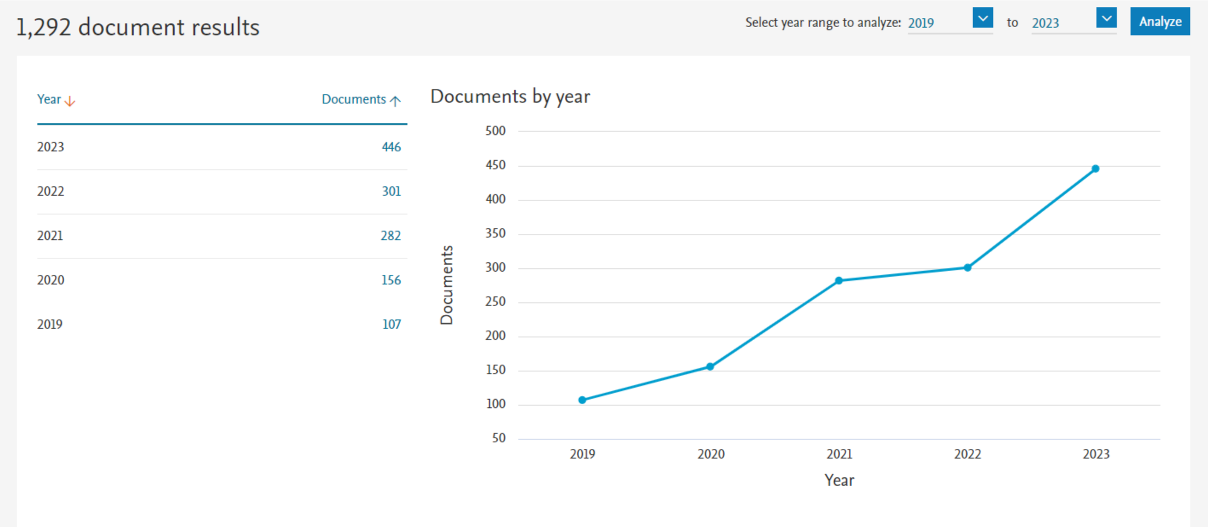
Elsevier Scopus was used as the search engine, which is a comprehensive database that provides access to a wide range of scholarly literature. The papers were identified by searching the keywords Artificial Intelligence and Pharmaceutical between 1st January 2019 and 31st December 2023. A total number of 1292 results were found.

TITLE-ABS-KEY (artificial AND intelligence AND pharmaceutical) AND PUBYEAR > 2018 AND PUBYEAR < 2024

3.1.2 Documents by year

Illustrated in Figure 3 is the overall count of publications spanning from 2019 to 2023. The year 2023 had the highest number of publications, whereas 2019 had the lowest. The findings reveal a noticeable upward trajectory over the last five years.

Figure 3 – Documents by year

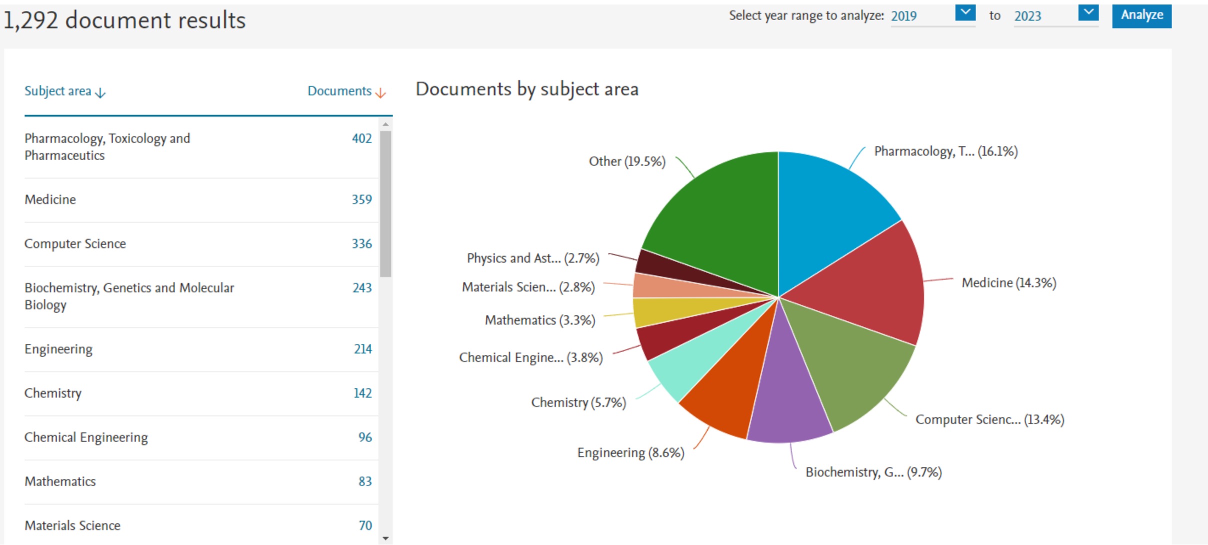


Source: Elsevier Scopus website

3.1.3 Documents by subject area

In Figure 4, the search results comprise a total of 1292 documents. When examining the distribution, 16.1% of these documents fall within the field of Pharmacology, Toxicology, and Pharmaceutics, making it the most prevalent category. Medicine follows closely with 14.3%, Computer Science account for 13.4% and Biochemistry with 9.7%. Other noteworthy contributions include Biochemistry, Genetics and Molecular Biology (9.7%), Engineering (8.6%) and Chemistry (5.7%).

Figure 4 – Documents by subject area



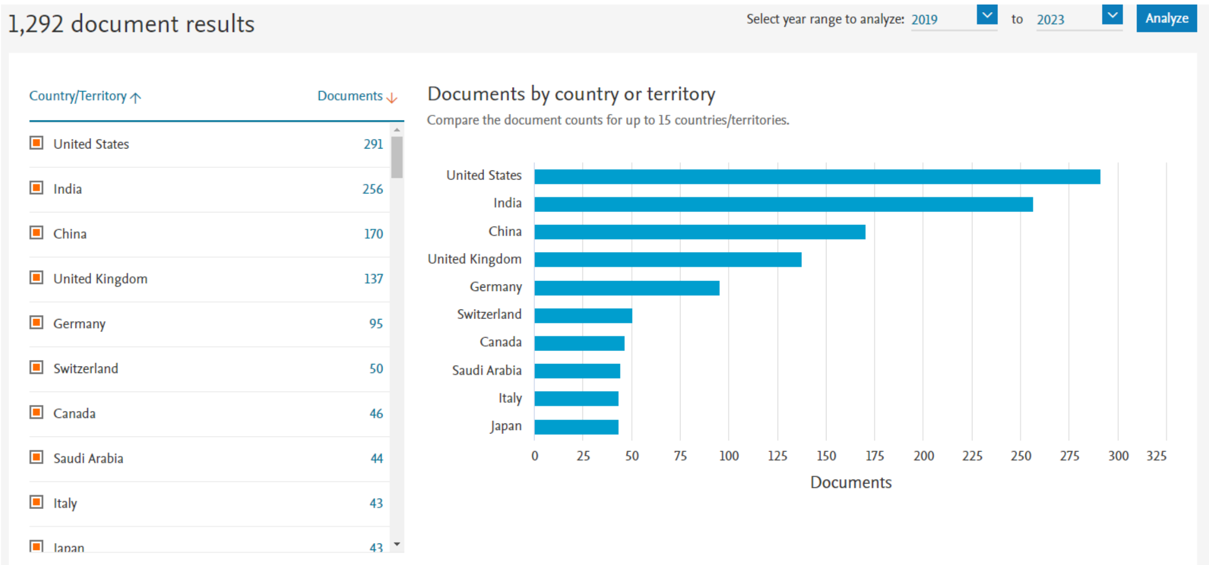
Source: Elsevier Scopus website

3.1.4 Documents by country

The findings presented in Figure 5 indicate that the predominant source countries for the documents retrieved through the search are the United States (291), India (256), China (170) and the United Kingdom (137). Following is Germany, contributing 95 documents, and the Switzerland with 50 documents.

These results highlight the global distribution of documents, with several countries making substantial contributions to the search findings.

Figure 5 – Documents by country

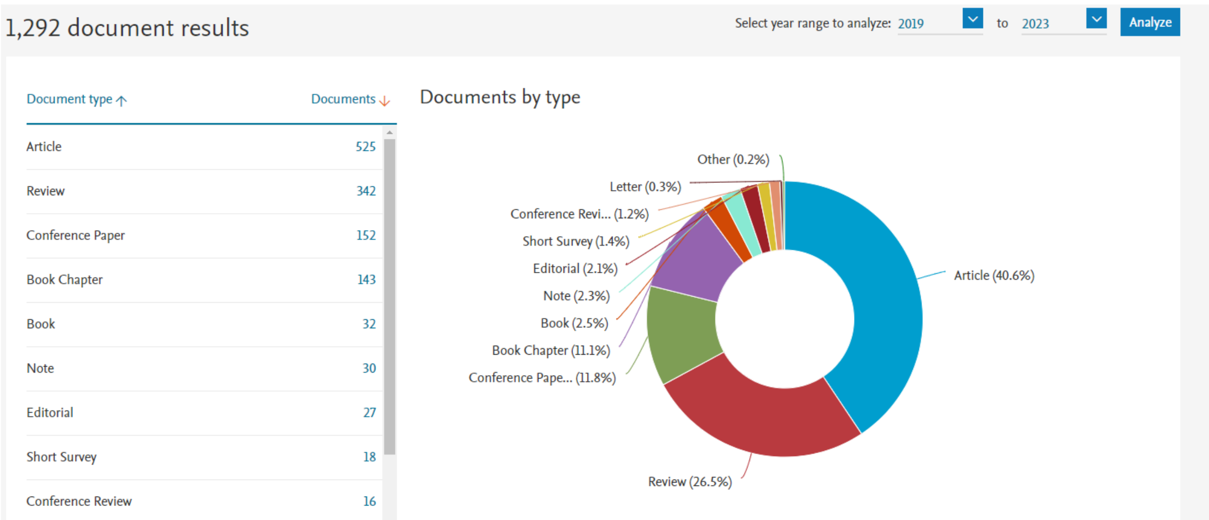


Source: Elsevier Scopus website

3.1.5 Documents by type

As reflected in the provided data, the breakdown of document types from the search results shows that the majority, 40.6%, are articles, followed by reviews at 26.5%. Conference papers account for 11.8%, book chapters represent 11.1%, and books make up 2.5% of the documents. Additionally, notes contribute 2.3%, while editorials 2.1%. Short surveys represent 1.4% and conference reviews 1.2% of the total documents.

Figure 6 – Documents by type

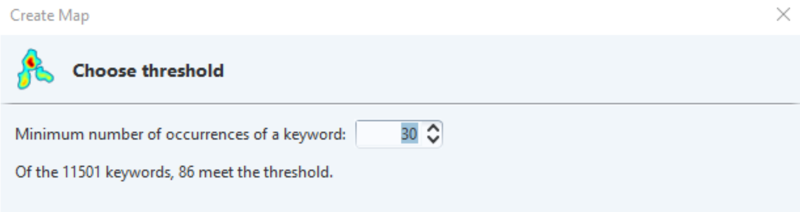


Source: Elsevier Scopus website

3.1.6 Keywords selection

The co-occurrence of keywords was mapped using VOS viewer on the dataset of the 1290 documents returned by the Scopus (2 documents were excluded because they were duplicated). This allows for the visualization of the network of the main keywords and provides information about thematic relationships and patterns in a specific research domain by grouping them into clusters. Figure 7 shows that 30 keywords were chosen from a total of 11501.

Figure 7 –Minimum number of occurrence of a keyword

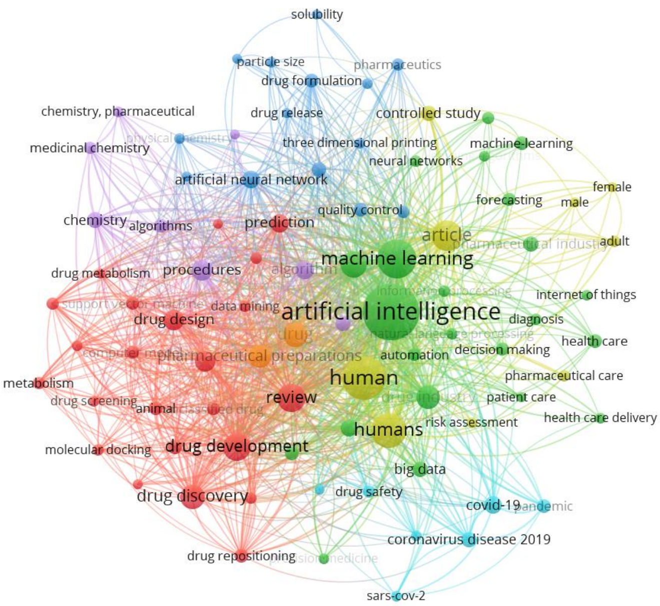


Source: Vos Viewer

3.1.7 Keyword co-occurrence map

The keyword co-occurrence map in Figure 8 enables the identification of a keyword frequency of occurrence based on its size. The bigger the word, the more common it is. Furthermore, the distance between two keywords indicates the strength of their co-occurrence relationship (Van Eck & Waltman, 2011).

Figure 8 – Co-occurrence map



Source – Vos Viewer

As illustrated in Figure 8, the term "Artificial Intelligence" stands out as the most commonly used keyword. Additionally, there is a notable association between "Artificial Intelligence" and the terms "machine learning" and "human," indicating a robust co-occurrence pattern in the analysed documents. This suggests that "Artificial Intelligence" frequently appears alongside either "human" or "machine learning" in the documents under examination.

In Table 1, the VOS viewer generated 7 clusters, each representing a set of keywords with a substantial co-occurrence relationship. This implies that keywords within the same cluster tend to appear together frequently in the analysed documents, whereas keywords from different clusters exhibit a less frequent occurrence when paired.

Table 1. Keywords Clusters

Cluster 1 (23 items)	Cluster 2 (23 items)	Cluster 3 (14 items)	Cluster 4 (9 items)	Cluster 5 (8 items)	Cluster 6 (7 items)	Cluster 7 (2 items)
animal ; animals; bioinformatics; chemical structure; computer model; conventional neural network; data mining; drug design; drug development; drug discovery; drug metabolism; drug repositioning; drug screening; high throughput screen; learning algorithm; metabolism; molecular docking; nonhuman; prediction; quantitative structure activity; review; support vector machine; unclassified drug	Artificial intelligence; automation; big data; decision making; deep learning; diagnosis; drug industry; drug research; forecasting; health care; health care delivery; information processing; internet of things; learning algorithms; learning systems; machine learning; machine-learning; natural language processing; neural networks; patient care; personalized medicine; pharmaceutical industry; precision medicine	Artificial neural network; drug delivery; drug delivery system; drug formulation; drug manufacture; drug release; drug solubility; in vitro study; particle size; pharmaceutics; physical chemistry; quality control; solubility; three dimensional printing.	Adult; article; controlled study; female; human; humans; male; pharmaceutical care; risk assessment	Algorithm; algorithms; chemistry; chemistry, pharmaceutical; neural networks, computer; priority journal; procedures	Clinical trial (topic); coronavirus disease 2019; covid-19; drug efficacy; drug safety; pandrmic; sars-cov-2	Drug; pharmaceutical preparation

Source: Self elaborated from Vos Viewer Data

3.2 Data analysis

3.2.1 Data cleaning

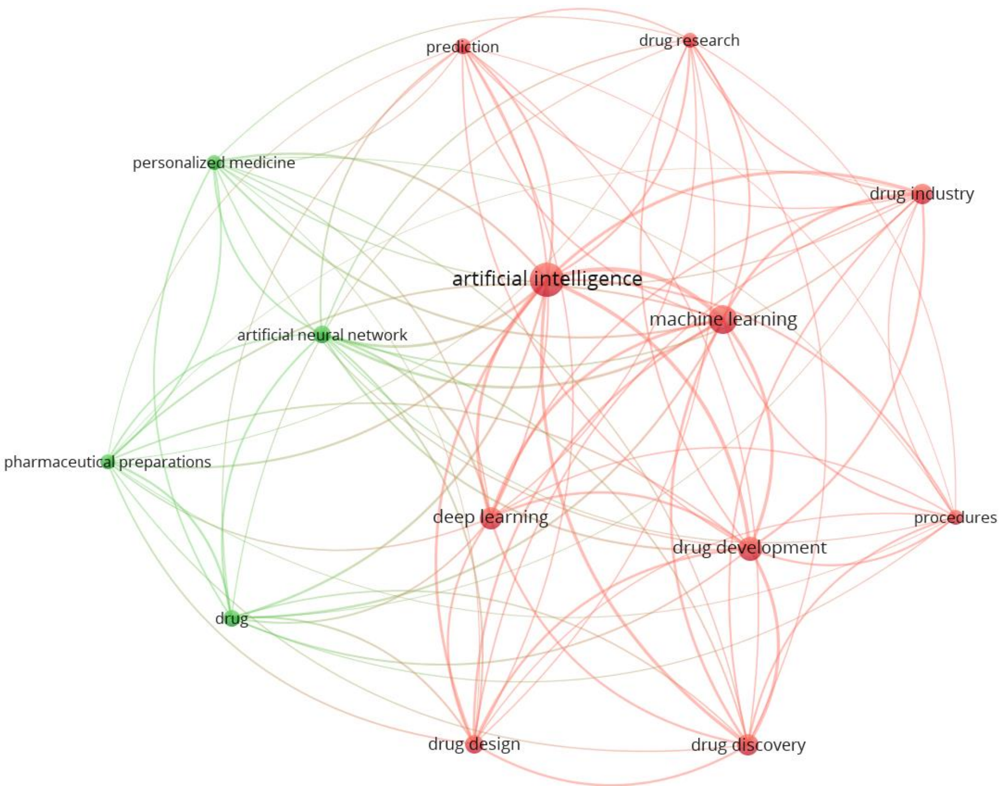
After removing duplicates and using filters of Elsevier Scopus of limit language to English, restricting subjects area and limiting the document type remained 658 papers. After that to guarantee the quality of the papers the data was restricted to papers with more than 10 citations, resulting in 164 papers. Of the 164 papers the full text was not available in 56 resulting in 108 papers. Within the read of the papers it was noticed that 47 should be excluded because they were highly specific studies related to some innovative therapy or specific innovative method not likely to impact the pharmaceutical business as a whole. The final result was 61 papers that are listed in the Annex A.

3.2.2 Main publication keywords

Through an examination of keywords extracted from the chosen articles, as depicted in Figure 8, the alignment with research questions and objectives has been improved. Subsequently, a text data-based map analysis was conducted to gauge the significance of these keywords, as illustrated in Figure 9. This map highlights the terms that hold greater relevance within the documents in Annex A.

The color gradations on the term map signify the density of terms, ranging from green indicating the lowest density to red representing the highest. Among the noteworthy terms are "artificial intelligence" "machine learning" “deep learning” and “drug development”. Additionally, the terms “human”, “humans”, “review” and “article” were excluded from consideration, as their inclusion was primarily due to their prevalence in article titles rather than their substantive relevance.

Figure 9. Keywords of articles selected



The term map analysis conducted using VOS viewer yielded two clusters, as outlined in Table 2 below. These two clusters encapsulate the dimensions of the bibliographic network.

Table 2. Term Map Clusters

Cluster 1 (10 items)	Cluster 2 (4 items)
Artificial intelligence ; deep learning; drug design; drug development; drug discovery; drug industry; drug research; machine learning; predicition ; procedures	Artificial neural network; drug; personalized medicine; pharmaceutical preparation

Source: Self elaborated from Vos Viewer Data

CHAPTER 4

Discussion and findings

This study is based on the research questions presented in the second chapter, the answers are presented bellow:

4.1 Research question 1

(Q1): What is the overall trend in academic publications related to the impact of artificial intelligence (AI) in the pharmaceutical business between 2019 and 2023?

The systematic literature review conducted for this master thesis aimed to discern the overall trend in academic publications concerning the impact of artificial intelligence (AI) in the pharmaceutical business from 2019 to 2023. The research objectives were meticulously designed to analyze publication trends, distribution across various sources, and geographical contributions during this specified timeframe.

The analysis of the data unequivocally reveals a notable upward trajectory in academic publications over the five-year period. Starting with the lowest point in 2019, the publications steadily increased each year, reaching a peak in 2023. This trend signifies a growing scholarly interest and engagement with the intersection of artificial intelligence and the pharmaceutical sector. The consistent climb in publications suggests that researchers, academics, and industry professionals are actively exploring, discussing, and disseminating knowledge regarding the impact of AI in the pharmaceutical sector.

The diversity in publication sources, including articles, reviews, conference papers, book chapters, and books, highlights the multidimensional nature of research in AI and pharmaceuticals. With articles constituting the majority, it is evident that researchers favor in-depth exploration and analysis. The presence of reviews indicates a scholarly inclination towards comprehensive discussions, while the inclusion of conference papers, book chapters, and books underlines the varied platforms where this knowledge is disseminated. This diverse distribution across publication sources attests to the richness and complexity of the academic discourse on AI in the pharmaceutical business.

The global perspective, as reflected in the geographical distribution of research output, underscores the collaborative and widespread interest in AI within the pharmaceutical sector. The leading contributions from the United States, India, China, the United Kingdom, Germany, and Switzerland indicate a global community of researchers actively contributing to the understanding of AI's impact on pharmaceuticals. This geographical diversity not only enriches the research landscape but also emphasizes the universal relevance of AI in reshaping the pharmaceutical industry.

In conclusion, the findings of this master thesis analysis demonstrate a clear and consistent upward trend in academic publications related to the impact of AI in the pharmaceutical business from 2019 to 2023. The increasing volume of research output, diverse publication sources, and global contributions collectively depict a field that is dynamically evolving and capturing the attention of scholars worldwide. The results of this study contribute valuable insights to the broader discourse on the intersection of artificial intelligence and the pharmaceutical business, informing future research directions and strategic considerations for stakeholders in academia and the pharmaceutical sector.

4.2 Research question 2

(Q2) What are the most cited and influential research articles in the domain of AI impact on the pharmaceutical business?

This chapter delves into the findings and results obtained through an in-depth exploration of the most cited and influential research articles in the domain of Artificial Intelligence (AI) impact on the pharmaceutical business. Utilizing a comprehensive dataset comprising articles from various aspects of AI application in pharmaceuticals, the chapter aims to distill key insights that contribute to a nuanced understanding of AI transformative role.

The dataset, encompassing ten pivotal articles, collectively unravels the multifaceted influence of AI across different dimensions of the pharmaceutical industry. The following articles in descending order of number of citations, elucidates specific facets of AI impact:

1-"Artificial intelligence in drug discovery and development" - Paul et al. (2021): This article, published in 2021, stands out with 375 citations, highlighting its significance in elucidating AI's transformative role in drug discovery and development within the pharmaceutical sector.

2-"Artificial intelligence in drug development: present status and future prospects" - Mak and Pichika (2019): With 361 citations, this foundational work from 2019 provides a comprehensive overview of AI's status and future trajectories in drug development, underscoring its enduring influence.

3-"Artificial intelligence to deep learning: machine intelligence approach for drug discovery" - Gupta et al. (2021): Published in 2021 and cited 305 times, this article captures the transition from artificial intelligence to deep learning, reflecting the evolving methodologies in drug discovery.

4-"Predictive Multitask Deep Neural Network Models for ADME-Tox Properties: Learning from Large Data Sets" - Wenzel et al. (2019): Focused on predictive models for ADME-Tox properties, this 2019 article, with 134 citations, sheds light on AI role in assessing drug safety and efficacy.

5-"Machine Learning in Drug Discovery: A Review" - Dara et al. (2022): This 2022 review, cited 125 times, offers a comprehensive overview of machine learning applications in drug discovery, emphasizing its rapid integration into contemporary research.

6-"Advances in de novo drug design: From conventional to machine learning methods" - Mouchlis et al. (2021): Published in 2021 and cited 115 times, this work explores the evolution from conventional to machine learning methods in de novo drug design.

7-"Current and Future Roles of Artificial Intelligence in Medicinal Chemistry Synthesis" - Struble et al. (2020): With 110 citations, this 2020 article delves into the roles of AI in medicinal chemistry synthesis, reflecting its recognition in reshaping traditional approaches.

8-"Lio-A Personal Robot Assistant for Human-Robot Interaction and Care Applications" - Miseikis et al. (2020): Published in 2020 and cited 109 times, this article introduces Lio, a personal robot assistant, signaling an expanded role of AI in healthcare beyond traditional drug discovery.

9-"Artificial intelligence in drug discovery: recent advances and future perspectives" - Jiménez-Luna et al. (2021): Published in 2021, this article, cited 95 times, provides insights into recent advances and future prospects in AI-driven drug discovery.

10-"Deep learning for in vitro prediction of pharmaceutical formulations" - Yang et al. (2019): This 2019 article, cited 90 times, focuses on deep learning for in vitro prediction of pharmaceutical formulations, highlighting its contribution to optimizing pharmaceutical formulations through advanced AI-driven predictive modeling.

Emerging Themes and Patterns

The analysis reveals several emerging themes and patterns within the realm of AI's impact on the pharmaceutical business:

Drug Discovery and Development Acceleration: Articles 1, 2, and 3 collectively emphasize AI pivotal role in accelerating drug discovery and development. Notably, they shed light on the areas of integration, tools, techniques, challenges, and collaboration strategies.

De Novo Drug Design and Machine Learning Applications: Articles 3, 6, and 10 highlight the transformative impact of AI, particularly machine learning, in de novo drug design. These articles underscore the utilization of AI algorithms in various drug discovery processes, including synthesis, screening, and prediction of pharmaceutical formulations.

Predictive Models for ADME-Tox Properties: Article 4 provides insights into the application of deep neural networks for predictive models related to absorption, distribution, metabolism, and toxicity (ADME-Tox) properties. This signifies AI contribution to optimizing compound properties crucial for successful drug discovery projects.

Machine Learning Applications in Clinical Trials: Article 5 focuses on the role of machine learning techniques in improving decision-making during clinical trials. It highlights the potential of AI in addressing challenges related to risk and expenditure in various phases of drug development.

AI in Medicinal Chemistry Synthesis and Beyond: Articles 7 and 8 showcase the expanding role of AI beyond traditional drug discovery, with a focus on medicinal chemistry synthesis and healthcare applications. These articles emphasize AI influence on reshaping conventional approaches within the pharmaceutical industry.

Recent Advances and Future Perspectives: Article 9 provides a comprehensive overview of recent advances and future perspectives in AI-driven drug discovery. It reflects the dynamic nature of advancements within the pharmaceutical industry, offering a forward-looking perspective.

This chapter synthesizes the key findings and results from an analysis of the most cited and influential research articles in the domain of AI impact on the pharmaceutical business. The identified articles collectively contribute to a rich understanding of how AI is reshaping drug discovery, development, and various facets of the pharmaceutical business. These insights lay the groundwork for subsequent discussions, implications, and recommendations in the broader context of the master thesis.

4.3 Research question 3

(Q3) How does the co-occurrence and clustering of keywords in academic literature reflect the evolving landscape of Artificial Intelligence applications in the pharmaceutical business, and what insights can be gained from the analysis of key clusters and their associated themes?

In the quest to understand the intricate relationship between Artificial Intelligence (AI) and the pharmaceutical industry, this research undertakes a comprehensive analysis of 61 selected articles. The exploration begins with the co-occurrence mapping of 30 keywords, providing a visual representation of the thematic connections within a dataset of 1,290 documents. This illuminates nuanced patterns and relationships within the intersection of AI and pharmaceuticals.

The term "Artificial Intelligence" emerges as the linchpin, prominently associated with "machine learning" and "human." The co-occurrence map (Figure 8) visually encapsulates the prevalence of these terms, offering insights into the dynamic interplay among them. Further granularity is achieved through the VOS viewer-generated keyword clusters, revealing seven distinct thematic groupings. Each cluster represents a constellation of keywords with substantial co-occurrence relationships, offering a systematic categorization of the literature.

Of particular interest is Cluster 1, which encompasses pivotal topics such as drug discovery, development, and machine learning. This symbiotic relationship between AI and these pharmaceutical domains forms a foundational theme. Cluster 2, focusing on artificial neural networks, personalized medicine, and pharmaceutical preparation, adds another layer of complexity, reflecting the multifaceted nature of AI impact on pharmaceuticals.

The subsequent data analysis, involving the meticulous curation of 108 papers post-cleaning and filtering, provides a refined selection for deeper exploration. The inclusion of 61 articles from Annex A adds richness to the dataset, offering diverse perspectives and insights. Titles such as "Artificial Intelligence in Drug Discovery and Development," "Digital Pharmaceutical Sciences," and "Machine Learning and Artificial Intelligence in Pharmaceutical Research and Development: A Review" signify the breadth and depth of the literature.

The synergy of VOS viewer application, keyword clustering, and refined data analysis sets the stage for a profound investigation into emerging research themes. Beyond the titles, the content of these articles unravels the dynamic landscape. The interplay of AI with drug design methodologies, the transformative applications of 3D printing, and the intricacies of pharmacovigilance emerge as key subtopics, reflecting the multifaceted nature of this intersection.

Aligned with the research objectives, this analysis not only categorizes subtopics within AI and pharmaceuticals but also unveils emerging themes. It positions us at the nexus of evolving trends, showcasing the challenges and opportunities inherent in the intersection of AI and the pharmaceutical business. This thesis serves as a comprehensive guide, providing a panoramic view of the dynamic landscape and offering valuable insights for future research and industry applications.

CHAPTER 5

Conclusions

This master thesis has undertaken a thorough investigation into the dynamic and evolving landscape of Artificial Intelligence (AI) applications within the pharmaceutical business. The exploration, guided by three key research questions, has provided nuanced insights into the trajectory, influential articles, and thematic clusters within this intersection.

Beginning with the examination of the overall trend in academic publications from 2019 to 2023, a compelling narrative emerges. The data unequivocally reveals a notable upward trajectory in academic publications over the five-year period. The consistent climb signifies a growing scholarly interest in the interplay between artificial intelligence and the pharmaceutical sector. The diverse distribution across publication sources, encompassing articles, reviews, conference papers, book chapters, and books, underscores the multidimensional nature of research in AI and pharmaceuticals. Moreover, the global perspective, evident in the geographical distribution of research output, emphasizes the collaborative and widespread interest in AI within the pharmaceutical sector. This geographical diversity not only enriches the research landscape but also underscores the universal relevance of AI in reshaping the pharmaceutical business.

The synthesis of influential research articles in the realm of AI impact on the pharmaceutical sector offers profound insights into the transformative potential of artificial intelligence within drug discovery, development, and broader industry applications. These articles collectively illuminate AI pivotal role in accelerating processes such as drug design, predictive modelling for compound properties, and enhancing decision-making in clinical trials. Moreover, they highlight the expanding horizons of AI, extending beyond traditional drug discovery to encompass medicinal chemistry synthesis and healthcare applications. As the pharmaceutical landscape continues to evolve, these findings underscore the dynamic nature of AI-driven advancements and provide a solid foundation for future research and strategic considerations within the field. Through a nuanced understanding of AI influence, stakeholders can leverage emerging technologies to navigate challenges and capitalize on opportunities, ultimately driving innovation and improving patient outcomes in the pharmaceutical domain.

This research provides a profound analysis of 61 selected articles, uncovering intricate connections between Artificial Intelligence (AI) and the pharmaceutical business. Through co-occurrence mapping and meticulous data analysis, thematic patterns within the AI-pharmaceutical nexus are revealed. The central role of "Artificial Intelligence" alongside "machine learning" and "human" is visually captured, while keyword clusters unveil distinct thematic groupings. With a refined selection of articles, diverse perspectives from Annex A enrich the analysis, exemplifying the extensive and insightful nature of the literature. Titles such as "Artificial Intelligence in Drug Discovery and Development" signify the richness of insights explored. Emerging themes, including AI's integration with drug design methodologies and transformative applications like 3D printing and pharmacovigilance, offer a profound understanding of this dynamic landscape.

The investigation into AI applications within the pharmaceutical business has not only provided insights into current trends but has also illuminated future directions for research in this domain. One notable trend is the increasing emphasis on leveraging AI for drug discovery acceleration, which has garnered significant attention from researchers and industry stakeholders alike. As technological advancements continue to enhance the capabilities of AI algorithms, future research endeavours may focus on optimizing these algorithms for more efficient and accurate drug discovery processes. Additionally, the exploration of AI applications in personalized medicine and pharmacovigilance underscores the potential for tailored interventions and enhanced safety monitoring within the pharmaceutical sector.

Moreover, the emergence of novel AI techniques, such as deep learning and natural language processing, presents exciting opportunities for advancing pharmaceutical research and development. Future investigations may delve into the integration of these techniques into existing workflows, exploring their potential to streamline processes and improve outcomes across various stages of drug development. Furthermore, as the volume and complexity of healthcare data continue to grow, there is a pressing need for research focused on data governance and standardization to ensure the reliability and interoperability of AI-driven solutions.

Considering these trends, future research efforts should aim to address several key areas of inquiry. Firstly, there is a need for longitudinal studies to assess the long-term impact of AI interventions on patient outcomes and healthcare delivery. Additionally, interdisciplinary collaborations between researchers, clinicians, and industry partners are essential for advancing AI-driven innovations in the pharmaceutical sector. Furthermore, investigations into ethical and regulatory considerations surrounding the use of AI in healthcare are paramount to ensure responsible and equitable deployment of these technologies.

Overall, the evolving landscape of AI applications in the pharmaceutical business offers a wealth of opportunities for future research and innovation. By addressing current challenges and exploring emerging trends, researchers can contribute to the continued advancement of AI-driven solutions in pharmaceutical research, development, and patient care.

In conclusion, this master thesis makes a significant contribution to the broader discourse on AI impact in the pharmaceutical business. The identified trends, influential articles, and emerging themes collectively serve as a comprehensive guide, offering a panoramic view of the dynamic landscape and providing valuable insights for future research and industry applications. As AI continues to permeate the pharmaceutical sector, this thesis lays a solid foundation for researchers, academics, and industry professionals to navigate the complexities of this transformative intersection, shaping the trajectory of future advancements and applications in the field.

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Annexes

Annex A – Article selection

Authors	**Title**	**Year**	**Cited by**	**Document type**
Paul, D. ; Sanap, G. ; Shenoy, S. ; Kalyane, D. ; Kalia, K. ; Tekade, R.K.	Artificial intelligence in drug discovery and development	2021	375	Article
Mak, K.-K. ; Pichika, M.R.	Artificial intelligence in drug development: present status and future prospects	2019	361	Article
Gupta, R. ; Srivastava, D. ; Sahu, M. ; Tiwari, S. ; Ambasta, R.K. ; Kumar, P.	Artificial intelligence to deep learning: machine intelligence approach for drug discovery	2021	305	Article
Wenzel, J. ; Matter, H. ; Schmidt, F.	Predictive Multitask Deep Neural Network Models for ADME-Tox Properties: Learning from Large Data Sets	2019	134	Article
Dara, S. ; Dhamercherla, S. ; Jadav, S.S. ; Babu, C.M. ; Ahsan, M.J.	Machine Learning in Drug Discovery: A Review	2022	125	Article
Mouchlis, V.D. ; Afantitis, A. ; Serra, A. ; Fratello, M. ; Papadiamantis, A.G. ; Aidinis, V. ; Lynch, I. ; Greco, D. ; Melagraki, G.	Advances in de novo drug design: From conventional to machine learning methods	2021	115	Article
Struble, T.J. ; Alvarez, J.C. ; Brown, S.P. ; Chytil, M. ; Cisar, J. ; Desjarlais, R.L. ; Engkvist, O. ; Frank, S.A. ; Greve, D.R. ; Griffin, D.J. ; Hou, X. ; Johannes, J.W. ; Kreatsoulas, C. ; Lahue, B. ; Mathea, M. ; Mogk, G. ; Nicolaou, C.A. ; Palmer, A.D. ; Price, D.J. ; Robinson, R.I. ; Salentin, S. ; Xing, L. ; Jaakkola, T. ; Green, W.H.; Barzilay, R. ; Coley, C.W. ; Jensen, K.F.	Current and Future Roles of Artificial Intelligence in Medicinal Chemistry Synthesis	2020	110	Article
Miseikis, J. ; Caroni, P. ; Duchamp, P. ; Gasser, A. ; Marko, R. ; Miseikiene, N. ; Zwilling, F. ; De Castelbajac, C. ; Eicher, L. ; Fruh, M. ; Fruh, H.	Lio-A Personal Robot Assistant for Human-Robot Interaction and Care Applications	2020	109	Article
Jiménez-Luna, J. ; Grisoni, F. ; Weskamp, N. ; Schneider, G.	Artificial intelligence in drug discovery: recent advances and future perspectives	2021	95	Article
Yang, Y. ; Ye, Z. ; Su, Y. ; Zhao, Q. ; Li, X. ; Ouyang, D.	Deep learning for in vitro prediction of pharmaceutical formulations	2019	90	Article

Baylon, J.L. ; Cilfone, N.A. ; Gulcher, J.R. ; Chittenden, T.W.	Enhancing Retrosynthetic Reaction Prediction with Deep Learning Using Multiscale Reaction Classification	2019	65	Article
Elbadawi, M. ; McCoubrey, L.E. ; Gavins, F.K.H. ; Ong, J.J. ; Goyanes, A. ; Gaisford, S. ; Basit, A.W.	Disrupting 3D printing of medicines with machine learning	2021	59	Article
Lamberti, M.J. ; Wilkinson, B.A. ; Donzanti ; Wohlhieter ; Parikh ; Wilkins ; Getz, K.	A Study on the Application and Use of Artificial Intelligence to Support Drug Development	2019	57	Article
Pérez Santín, E.; Rodríguez Solana, R. ; González García, M. ; García Suárez, M.D.M. ; Blanco Díaz, G.D. ; Cima Cabal, M.D. ; Moreno Rojas, J.M. ; López Sánchez, J.J.	Toxicity prediction based on artificial intelligence: A multidisciplinary overview	2021	50	Article
Nayarisseri, A. ; Khandelwal, R. ; Tanwar, P. ; Madhavi, M. ; Sharma, D. ; Thakur, G. ; Speck-Planche, A. ; Singh, S.K.	Artificial intelligence, big data and machine learning approaches in precision medicine & drug discovery	2021	47	Article
Kolluri, S. ; Lin, J. ; Liu, R. ; Zhang, U. ; Zhang, W.	Machine Learning and Artificial Intelligence in Pharmaceutical Research and Development: a Review	2022	46	Article
Damiati, S.A.	Digital Pharmaceutical Sciences	2020	43	Article
Schmider, J. ; Kumar, K. ; Laforest, C. ; Swankoski., B. ; Naim, K. ; Caubel, P.M.	Innovation in Pharmacovigilance: Use of Artificial Intelligence in Adverse Event Case Processing	2019	40	Article
McComb, M. ; Bies, R. ; Ramanathan, M.	Machine learning in pharmacometrics: Opportunities and challenges	2022	40	Article
Patel, V. ; Shah, M.	Artificial intelligence and machine learning in drug discovery and development	2002	34	Article
Schwaller, P. ; Vaucher, A.C. ; Laplaza, R. ; Bunne, C. ; Krause, A. ; Corminboeuf, C. ; Laino, T.	Machine intelligence for chemical reaction space	2022	33	Article
Karalia, D. ; Siamidi, A. ; Karalis, V. ; Vlachou, M.	3d-printed oral dosage forms: Mechanical properties, computational approaches and applications	2021	30	Article
Thakur, A. ; Mishra, A.P. ; Panda, B. ; Rodríguez, D.C.S. ; Gaurav, I. ; Majhi, B.	Application of artificial intelligence in pharmaceutical and biomedical studies	2020	28	Article
Blanco-González, A. ; Cabezón, A. ; Seco-González, A. ; Conde-Torres, D. ; Antelo-Riveiro, P. ; Piñeiro, Á. ; Garcia-Fandino, R.	The Role of AI in Drug Discovery: Challenges, Opportunities, and Strategies	2023	24	Article
Sturm, N. ; Mayr, A. ; Le Van, T. ; Chupakhin, V. ;	Industry-scale application and evaluation of deep learning for drug target prediction	2020	23	Article

Ceulemans, J. ; Wegner, J. ; Golib-Dzib, J.-F. ; Jeliazkova, N. ; Vandriessche, Y. ; Böhm,S. ; Cima, V. ; Martinovic, J. ; Greene, N. ; Vander Aa, T. ; Ashby, T.J. ; Hochreiter, S. ; Engkvist, O. ; Klambauer, G. ; Chen, H.				
Lewis, D.J. ; McCallum, J,F,	Utilizing Advanced Technologies to Augment Pharmacovigilance Systems: Challenges and Opportunities	2020	23	Article
Selvaraj, C. ; Chandra, I. ; Singh, S.K.	Artificial intelligence and machine learning approaches for drug design: challenges and opportunities for the pharmaceutical industries	2022	22	Article
Kot, S. ; Hussain; H.I. ; Bilan, S. ; Haseeb, M. ; Mihardjo, L.W.W.	The role of artificial intelligence recruitment and quality to explain the phenomenon of employer reputation	2021	22	Article
Griffen, E.J. ; Dossetter, A.G. ; Leach, A.G.	Chemists: AI Is Here; Unite to Get the Benefits	2020	20	Article
Koren, G. ; Nordon, G. ; Radinsky, K. ; Shalev, V.	Clinical pharmacology of old age	2019	20	Article
Lou ; Wu, L.	AI on drugs: can artificial intelligence accelerate drug development? evidence from a large-scale examination of bio-pharma firms	2021	19	Article
Vora, L.K. ; Gholap, A.D. ; Jetha, K. ; Thakur, R.R.S. ; Solanki, H.K. ; Chavda, V.P.	Artificial Intelligence in Pharmaceutical Technology and Drug Delivery Design	2023	19	Article
Moulin, P. ; Grünberg, K. ; Barale-Thomas, E. ; der Laak, J.V.	IMI—Bigpicture: A Central Repository for Digital Pathology	2021	19	Article
Finelli, L.A. ; Narasimhan, V.	Leading a Digital Transformation in the Pharmaceutical Industry: Reimagining the Way We Work in Global Drug Development	2020	19	Article
Nelson, S.D. ; Walsh, C.G. ; Olsen, C.A. ; McLaughlin, A.J. ; LeGrand, J.R. ; Schutz, N. ; Lasko, T.A.	Demystifying artificial intelligence in pharmacy	2020	18	Article
Hirschberg, C. ; Edinger, M. ; Holmfred, E. ; Rantanen, J. ; Boetker, J.	Image-based artificial intelligence methods for product control of tablet coating quality	2020	18	Article
Sharma, R. ; Singh, D. ; Gaur, P. ; Joshi, D.	Intelligent automated drug administration and therapy: future of healthcare	2021	18	Article
Alemayehu, D. ; Hemmings, R. ; Natarajan, K. ; Roychoudhury, S.	Perspectives on Virtual (Remote) Clinical Trials as the “New Normal” to Accelerate Drug Development	2022	18	Article
Rohall, S.L. ; Auch, L. ; Gable, J. ; Gora, J. ; Jansen, J. ; Lu, Y. ; Martin, E. ; Pancost-Heidebrecht, M. ; Shirley, B. ; Stiefl, N. ; Lindvall, M.	An artificial intelligence approach to proactively inspire drug discovery with recommendations	2020	17	Article

Cerchia, C. ; Lavecchia, A.	New avenues in artificial-intelligence-assisted drug discovery	2023	17	Article
Muhindo, D. ; Elkanayati, R. ; Srinivasan, P. ; Repka, M.A. ; Ashour, E.A.	Recent Advances in the Applications of Additive Manufacturing (3D Printing) in Drug Delivery: A Comprehensive Review	2023	17	Article
Kinkorová, J.	Education for future biobankers - The state-of-the-art and outlook	2021	16	Article
Noor, F. ; Asif, M. ; Ashfaq, U.A. ; Qasim, M. ; Tahir Ul Qamar, M.	Machine learning for synergistic network pharmacology: a comprehensive overview	2023	16	Article
Wang, S. ; Di, J. ; Wang, D. ; Dai, X. ; Hua, Y. ; Gao, X. ; Zheng, A. ; Gao, J.	State-of-the-Art Review of Artificial Neural Networks to Predict, Characterize and Optimize Pharmaceutical Formulation	2022	16	Article
Abramov, Y.A. ; Sun, G. ; Zeng, Q.	Emerging Landscape of Computational Modeling in Pharmaceutical Development	2022	15	Article
Thompson, D.C. ; Bentzien, J.	Crowdsourcing and open innovation in drug discovery: recent contributions and future directions	2020	14	Article
Azab, E. ; Nafea, M. ; Shihata, L.A. ; Mashaly, M.	A machine-learning-assisted simulation approach for incorporating predictive maintenance in dynamic flow-shop scheduling	2021	13	Article
Furtner, D. ; Shinde, S.P. ; Singh, M. ; Wong, C.H. ; Setia, S,	Digital Transformation in Medical Affairs Sparked by the Pandemic: Insights and Learnings from COVID-19 Era and Beyond	2022	13	Article
Velmurugan, D. ; Pachaiappan, R. ; Ramakrishnan, C	Recent trends in drug design and discovery	2020	13	Article
Grebner, C. ; Matter, H. ; Kofink, D. ; Wenzel, J. ; Schmidt, F. ; Hessler, G.	Application of Deep Neural Network Models in Drug Discovery Programs	2021	12	Article
Sahu, A. ; Mishra, J. ; Kushwaha, N.	Artificial Intelligence (AI) in Drugs and Pharmaceuticals	2022	12	Article
Melnykova, N. ; Shakhovska, N. ; Gregus, M. ; Melnykov, V. ; Zakharchuk, M. ; Vovk, O.	Data-driven analytics for personalized medical decision making	2020	12	Article
Bhattamisra, S.K. ; Banerjee, P. ; Gupta, P. ; Mayuren, J. ; Patra, S. ; Candasamy, M.	Artificial Intelligence in Pharmaceutical and Healthcare Research	2023	11	Article
Liu, X. ; Meehan, J. ; Tong, W. ; WuY, L. ; Xu, X. ; Xu, J	DLI-IT: A deep learning approach to drug label identification through image and text embedding	2020	11	Article
Kumar, S.A. ; Ananda Kumar, T.D. ; Beeraka, N.M. ; Pujar, G.V. ; Singh, M. ; Narayana Akshatha, H.S. ; Bhagyalalitha, M.	Machine learning and deep learning in data-driven decision making of drug discovery and challenges in high-quality data acquisition in the pharmaceutical industry	2022	11	Article
Algorri, M. ; Cauchon, N.S. ; Abernathy, M.J.	Transitioning Chemistry, Manufacturing, and Controls Content With a Structured Data Management Solution: Streamlining Regulatory Submissions	2020	11	Article

Jiang, J. ; Ma, X. ; Ouyang, D. ; Williams, R.O.	Emerging Artificial Intelligence (AI) Technologies Used in the Development of Solid Dosage Forms	2022	10	Article
Ferreira, L.L. ; Andricopulo, A.D.	From chemoinformatics to deep learning: An open road to drug discovery	2019	10	Article
Nguyen, A. ; Pellerin, R. ; Lamouri, S. ; Lekens, B.	Managing demand volatility of pharmaceutical products in times of disruption through news sentiment analysis	2023	10	Article
Ahluwalia, K. ; Abernathy, M.J. ; Beierle, J. ; Cauchon, N.S. ; Cronin, D. ; Gaiki, S. ; Lennard, A. ; Mady, P. ; McGorry, M. ; Sugrue-Richards, K. ; Xue, G.	The Future of CMC Regulatory Submissions: Streamlining Activities Using Structured Content and Data Management	2022	10	Article
Hariry, R.E. ; Barenji, R.V. ; Paradkar, A.	Towards Pharma 4.0 in clinical trials: A future-orientated perspective	2022	10	Article