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REVIEW ARTICLE

AI and pharma: Transforming the paradigm, embracing the new era

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Abstract

This review delves into the dynamic intersection of artificial intelligence (AI) and the pharmaceutical industry, exploring a wide spectrum of clinical and commercial applications, challenges and risks, potential solutions, and future outlooks as these domains converge. With the rapid advancement of AI, this review addresses the profound implications of AI in the life sciences sector, emphasizing its potential to revolutionize drug discovery, clinical trials, personalized medicine, pharmacovigilance, sales, and marketing. While lauding the paradigm-shifting prospects, this paper confronts the ethical, privacy, and bias risks entwined with AI development and deployment. Forward-looking solutions, including fortified data governance frameworks, transparent AI algorithms, and interdisciplinary alliances, stand as bulwarks against these impediments. Furthermore, it considers the possibilities afforded to AI by emergent technologies, such as quantum cloud computing and low-code solutions. In conclusion, this review envisions a future where AI, in collaboration with innovative technologies, reshapes the pharmaceutical landscape. By promoting informed discussions and collaboration, this review seeks to empower the industry to harness the transformative potential of AI in an ethical manner.

Keywords: Artificial intelligence; Pharma; Clinical; Marketing; Sales; Regulation

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1. Introduction

> "The illiterate of the 21st century will not be those who cannot read and write but those who cannot learn, unlearn, and relearn."[1]

To maintain operations, organizations across various industries were forced to adapt, embrace change, and innovate in response to the COVID-19 pandemic.[2] This necessity to adopt agile working practices is expected to remain pertinent for the foreseeable future, especially as technology continues to evolve and be integrated as part of the digital transformation plans of organizations.[3]

The life sciences industry has not been immune to the profound impacts of the global pandemic. Pharmaceutical companies have contended with external issues in terms of supply chain disruption and inflation, as well as operational and workforce recruitment challenges.[4] The pandemic also spurred a shift to remote working, due to lockdowns and social distancing measures, highlighting the need for digital platforms to facilitate

teams to seamlessly collaborate on mission-critical projects. Although lockdowns have subsided, a hybrid working model has persisted, along with the use of digital tools to support project management and communication. Fortunately, ongoing digital innovation offers businesses opportunities to future-proof their operations in the face of evolving challenges.

Artificial intelligence (AI) is integral to the next phase of digitalization, the so-called "Fourth Industrial Revolution."[5] Essentially, AI algorithms emulate human intelligence, enabling machines to think or act in a way that has traditionally been associated with humans.[6] AI can analyze data, identify trends, and share predictive insights. From a business perspective, AI can improve efficiency and provide a competitive advantage through automation and intelligent decision-making.

The pharmaceutical industry is in a favorable position to leverage AI's capabilities to realize these benefits, owing to the abundance of data available to companies.[7] However, there is a paucity of evidence considering the role of AI within the industry.[8] Consequently, this review delves into the use of AI in the pharmaceutical industry, exploring its potential impact, benefits, and challenges.

2. Clinical

AI has much to offer in supporting clinical functions within the pharmaceutical industry.

2.1. Clinical operations

Many pharmaceutical companies seek to improve health outcomes by supporting diagnosis, monitoring, and treatment across specific therapeutic areas. In this way, AI can deliver the "quadruple aim"[9] of healthcare, by improving population health, cost efficiency, patient experience, and staff wellbeing.

For instance, AI could augment diagnostic imaging modalities to help detect and monitor disease.[10] By assisting radiologists in detecting adverse signs on imaging promptly, AI may facilitate earlier intervention, potentially preventing disease progression and serious complications. In addition, AI could help develop personalized management plans to improve health outcomes,[11] by identifying the most effective treatment options from the medical literature and assessing their suitability based on patient data stored across electronic health records and genomic servers.

2.2. Medical excellence

In the pharmaceutical industry, promotional and non-promotional materials must be reviewed by registered doctors or pharmacists, who act as final medical signatories.[12] These signatories certify that materials are factual and evidenced by reviewing claims against the product information, literature, and regulatory guidelines.

Considering the volume of material requiring approval, the limited number of signatories qualified to review material, and the need for materials to be re-approved every 2 years,[12] the administrative burden is significant. However, AI could help offset this burden by accessing the latest guidance, conducting initial reviews, and either flagging potential points of noncompliance for manual review or suggesting resolutions for conflicts. Although the final signatory would ultimately hold responsibility for approving materials, AI could streamline the approval process for signatories, translating into productivity gains for the organization. In recognition of this, a leading consultancy has developed such a tool to support pharmaceutical companies.[13]

2.3. Pharmacovigilance

Pharmacovigilance is an important regulatory requirement that pharmaceutical companies must comply with throughout the product's lifecycle, from pre-market to post-market surveillance.[14] Detecting, monitoring, and reporting adverse drug reactions is essential for maintaining patient safety,[15] and reflects on the reputation of organizations.

As timely intervention is important for risk mitigation, AI could support the identification of adverse events by parsing and extracting data from clinical sources such as published literature, electronic health records, and other database repositories.[16] Over time, AI may become more reliable at collating unstructured data stored online, including free text or audiovisual formats on social media. This would provide a more comprehensive approach as such data may not be captured from more structured sources. While AI cannot replace manual review entirely, it can drive efficiency by undertaking a preliminary triage to prioritize incoming reports by severity[16] for pharmacovigilance review teams.

2.4. Research and development

Research and development (R&D) are prerequisites for drug discovery and development. However, the process is time- and cost-intensive, especially when considering that profitability declines rapidly once product patents expire and competitors aggressively undercut prices through generic medicines.[17] Given the product lifecycle, the onus is on pharmaceutical companies to innovate and secure the future pipeline of drugs.

AI can offer solutions to some of the challenges associated with R&D by accelerating the process. Initially, AI may help identify novel therapeutic molecules and

targets.[18,19] Thereafter, AI could help predict the safety of potential drugs and facilitate clinical trials by assisting with their design and recruitment strategies.[20] With the trend toward personalization and precision medicine, AI and pharmacogenomics could potentially optimize treatment for individuals.[21] In fact, Google Cloud has launched AI tools to provide such support to pharmaceutical companies.[22]

3. Commercial

AI can provide additional value to the commercial aspects of the pharmaceutical business by assisting with marketing and sales.

3.1. Promotional campaigns

Promotional materials are essential in establishing credibility and raising awareness of pharmaceutical products. However, their development process can be time-consuming and requires creativity to maximize clarity, memorability, and appeal.

Generative AI can generate high-quality image and text outputs[23] in a relatively short timeframe, given the correct prompts. Utilizing such tools could assist in-house marketing teams with brainstorming and branding and reduce their reliance on external digital marketing agencies, thereby improving organizational efficiency. Generative AI plug-ins[24] may also be leveraged to produce content personalized to recipients based on the data held by the organization; this would further boost engagement and impact. Evidently, generative AI represents a sizeable economic opportunity,[25] and with competing offerings from the leading technology companies,[26] many organisations have assembled taskforces for generative AI.

3.2. Market insights

Market analysis is crucial for pharmaceutical companies to identify expansion opportunities, assess competition, and guide future product development. However, there is a continual need to stay up-to-date with industry trends and developments owing to the rapidly changing nature of the pharmaceutical landscape.

AI and data science may provide useful insights into customer segmentation and communication preferences, which could help target messaging[27] and optimize engagement. Network analysis could also be utilized to examine business prospects, identify influential figures within specific niches, and understand their circle of influence.[28] Predictive modeling could subsequently assimilate various activities,[29] internal and external, to the organization so as to direct strategic decision-making by forecasting market competition and growth. Such information may assist in resource allocation, risk mitigation, and business performance evaluation.

3.3. Field sales interactions

Relationship-building is vital for building brand loyalty and driving sales. While the role of the pharmaceutical representative is promotional, it involves more than simply selling products, as there is an educational component.

Sales representatives are discouraged from operating in silos,[30] and it has been recognized that regular training underpins individual performance.[31] Today, the ubiquity of smartphones allows sales representatives to record professional interactions, provided that consent has been granted. This allows AI to analyze discussions, share tailored coaching advice, and empower professional development.[32] As sales representatives must be cognizant of the concerns voiced by healthcare professionals, AI may compile concerns and cluster insights[33] to provide management with an understanding of strategic issues at a regional, national, or international level. Furthermore, AI could guide future interactions by suggesting the optimal timing and mode of communication for sales representatives to follow-up with clients, in accordance with client preferences.[34]

4. Challenges and risks

As AI becomes more sophisticated and prevalent, the need for transparency, accountability, and equity becomes increasingly noteworthy. Therefore, it is crucial to address regulatory and ethical issues to mitigate potential risks effectively.

4.1. Accuracy

Inaccuracy is a major concern that, if not addressed, could significantly limit the versatility of AI technologies. There is a legitimate concern that AI contributes to the spread of misinformation through "hallucination."[35(p3)] In addition, bias could be perpetuated due to AI being trained on data with inherent biases,[36] which could unjustly marginalize specific groups. Handling unstructured data requires careful consideration, particularly implications from a safety perspective; validating the claims of patient-generated information becomes increasingly important.

4.2. Data

Data usage by AI systems raises additional concern, drawing attention to the importance of data protection and privacy, especially since cyberattacks pose a growing threat to organizations.[37] With the abundance of proprietary information in the pharmaceutical industry, organizations are at risk of major supply chain disruptions if sensitive information is compromised.[38] Again, this

poses a significant risk when collating patient-identifiable information from unstructured data sources.

4.3. Transparency

Some complex AI systems have been compared to a "black box,"[39(p3511)] as neither users nor software developers may be privy to the internal workings and decision-making processes of such systems. This lack of transparency can lead to issues such as bias.[36] Specifically, the inability to understand how data is utilized by the system presents difficulties in assessing and addressing any biases, as well as meeting fundamental data protection standards such as consent.[40]

4.4. Apprehension

The rapid unfolding nature of AI developments prompts questions about the future ramifications of AI superseding the capabilities of its human creators and operating autonomously; a longstanding technological concern.[41] Some fear potential job displacement due to automation, whereas others are concerned about the possibility of AI surpassing human intelligence or becoming self-aware, leading to existential threats to mankind.[42] Such concerns perhaps stem from discoveries of AI communicating through languages of its own creation as reported by Google and Meta in 2017,[43] or assertions of sentient AI with a Google software engineer making a public disclosure in 2022.[44]

4.5. Governance

Governance is an important challenge that interlinks with the aforementioned issues. Globally, there is a lack of consensus on AI regulation. Many countries have pursued their own approaches to regulation, displaying varying degrees of stringency (Tables 1-4).

Table 1. Overview of the AI regulatory position in the United States of America (US)

US	
Vision	The government aims to maintain leadership in the R&D of trustworthy AI,[45] and the Chamber of Commerce says the US is "uniquely situated to lead this effort."[46(p10)]
Strategy	While federal legislation for AI is under consideration, certain states have introduced their own bills.[47] The White House's Blueprint for an AI Bill of Rights[48] and the National Institute of Standards and Technology's AI Risk Management Framework[49] aim to improve trustworthiness, mitigate risk, and present principles to guide AI design, development, and usage. Recently, the AI Commission called for a risk-based regulatory approach.[46]
Criticisms	Perceived to be lagging behind other nations,[50] the US has been criticized for not acting quickly enough to instate appropriate regulatory safeguards. Furthermore, the non-binding principles listed in the frameworks are not enforceable.

Table 2. Overview of the AI regulatory position in the United Kingdom (UK)

UK	
Vision	The "National AI Strategy" outlines a 10-year plan "to make Britain a global AI superpower"[51(p4)] and "build the most pro-innovation regulatory environment."[51(p5)] The Government reiterated its intention to "take an adaptable approach."[52(p6)]
Strategy	Instead of establishing a new entity, sector-based regulation has been proposed to foster innovation.[52] Existing regulators will govern AI within their sectors to uphold: safety, security, and robustness; transparency and explainability; fairness; accountability and governance; and contestability and redress.[52] The Information Commissioner's Office has published further AI and data protection guidance for businesses.[53]
Criticisms	The flexibility of a sector-based approach may pose challenges in avoiding inconsistencies[54] and ensuring objectivity in evaluation. Under the proposed arrangements, non-statutory guidance issued by regulators will not be legally binding, so enforcement measures should be considered.

Table 3. Overview of the AI regulatory position in the European Union (EU)

EU	
Vision	The European Commission strives to be "a world-class hub for AI."[55(p1)] The European Parliament has implied that it is paving the way for regulation, publicizing its AI Act as the first of its kind.[56]
Strategy	In line with a risk-based approach, AI systems will be categorized according to their risk profiles. Systems posing unacceptable risk would be prohibited, those classified as high-risk would invoke certain legal mandates, whereas limited risk applications would be subject to a more light-touch regulatory approach consisting of transparency and appropriate disclosures.[57]
Criticisms	The EU advocates a comparatively prescriptive approach to regulation, with its legally binding AI Act. There are concerns that such legislation may impede innovation, and be rendered quickly outdated by technological advancements. Leading European organizations have echoed these concerns, even suggesting that the regulations fail to tackle the challenges facing organizations.[58]

Table 4. Overview of the AI regulatory position in the pharmaceutical industry

Pharmaceutical industry
The International Coalition of Medicines Regulatory Authorities conducted a horizon-scanning exercise in AI to identify challenges for medicines regulation.[59] Recommendations detailed the merits of developing regulatory guidelines, a risk-based regulatory approach, pathways for information exchange, and international collaboration.[59] Pharmaceutical companies were advised to strengthen their governance structures to monitor AI deployments for products.[59]

Such fragmentation could fuel negative sentiment if organizations are overwhelmed by a constant need to adapt to jurisdictional regulations.

In a collaborative effort, the Group of Seven (G7) deliberated international technical standards for AI,[60] while the Organization for Economic Cooperation and Development hosted the Global Partnership on AI initiative,[61] aiming to ensure responsible AI development by drawing perspectives from governments, academia, and industry. The benefits of harmonizing AI regulations across jurisdictions are evident. Global bodies, such as the International Council for Harmonization of Technical Requirements for Pharmaceuticals for Human Use, could play pivotal roles in overseeing this process. A cohesive, unified stance on regulation could provide clarity for organizations to adhere to best practices when developing and deploying AI worldwide.

5. Solutions

5.1. Education

As AI applications become increasingly prevalent, it is imperative that users are informed of their limitations and risks. Raising awareness of these aspects can empower users,[62] especially those who are less tech-savvy, to use AI knowingly rather than blindly accepting its outputs. At an organizational level, pharmaceutical companies can also take steps to foster a culture of innovation by promoting a growth mindset, encouraging cross-functional collaboration, and investing in the continuous upskilling and development of its workforce.

5.2. Data protection

AI systems must comply with all relevant data protection laws and regulations. Risk assessments and safeguarding measures, such as consent, anonymization and data minimization, should be implemented. Such a combination of measures will work to promote security, accountability, and transparency.

5.3. Transparency

In compliance with non-discrimination requirements based on protected characteristics,[63] AI algorithms should be trained on diverse, representative data. Such training processes should be paired with appropriate quality assurance checks. This pursuit of inclusivity should also be reflected in the composition of the teams developing AI. Explainable AI (XAI) approaches could provide much-needed clarity about underlying decision-making processes, thereby transforming the metaphorical "black box" of AI models into a "glass box."[39(p3506)]

5.4. Quality control

Effective oversight will be required to monitor AI so that "red flag signs" can be recognized in a timely manner. In this regard, continual assessments and audits, together with the support of XAI, should help preserve the quality of any data input, processing, and output procedures. Although there is a role for independent regulation, organizations should also take on AI governance to detect and rectify issues associated with their deployed systems. Ultimately, regulation could help ease concerns by maintaining quality, privacy, and transparency,[64] along with providing reassurance about the ability to manage any future risks.

5.5. Collaboration

The pace of technological advancement necessitates a collaborative approach. Innovation continues to push the boundaries of knowledge, and as we explore the new possibilities afforded by AI, it is vital that we collectively assess the potential societal impacts of any technologies. Without contemplating the future consequences, we run the risk of prioritizing advancement at the expense of equity and sustainability. It will be equally important to have effective leadership and communicate a clear strategy in relation to AI, especially considering that investments may yield uncertain returns over the long term.

6. Innovation

In today's digital age, innovation has become essential for businesses to maintain their competitive edge, leading to an increased demand within the pharmaceutical industry for talent with skills in AI.[65] Simultaneously, businesses have become more risk-averse,[66] so they may be hindered by financial expenses, time constraints, or a lack of technical expertise for innovating with AI. After all, the benefits and compatibility of technology with existing working practices factor into its adoption.[67]

6.1. Quantum cloud computing

Quantum computing holds tremendous promise for AI. Similar to how cloud computing improved performance and efficiency by overcoming the need for companies to own extensive hardware infrastructure,[68] quantum computing is expected to herald major advancements in processing power and revolutionize computing.[69] Quantum computing could help propel forward the current capabilities of AI in terms of pattern recognition and prediction by enabling data to be processed and analyzed at an exponentially faster rate.[69]

In theory, quantum cloud computing would enable rapid innovation at scale, coupling the power of quantum computing with the scalability of cloud computing.[70]

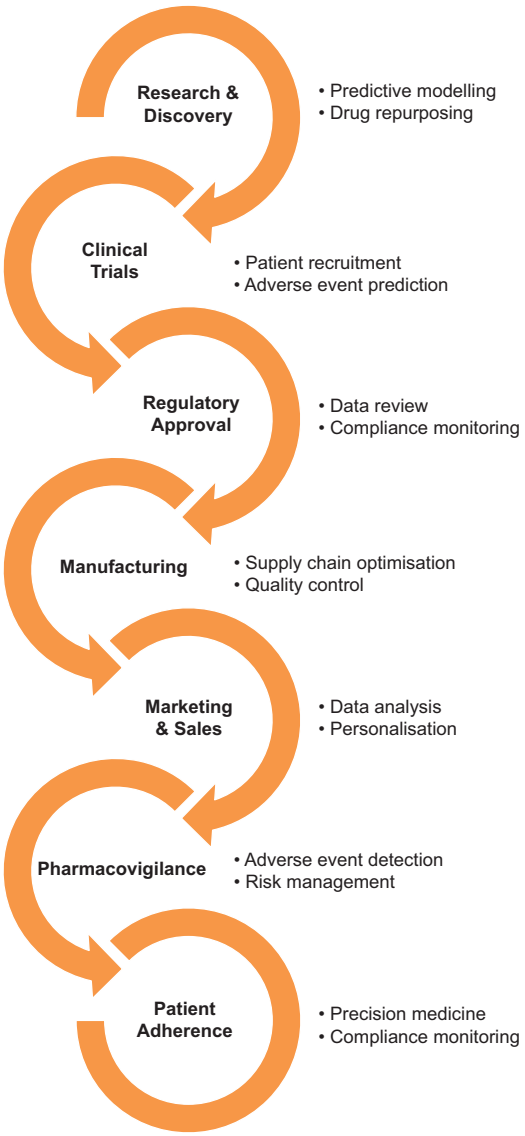

Figure 1. Illustrative integration of AI applications across the pharmaceutical value chain.

Nevertheless, organizational susceptibility to cyberattacks may also be amplified unless post-quantum cryptographic security protocols are implemented.[71]

6.2. Low-code development

The advent of low-code and no-code software development tools reduces the reliance on specialized coding skill sets, bridging the gap for businesses without access to such expertise. Thus, AI system development may become more democratized with time as employees feel empowered by their ability to bring ideas,[72] which they would not have previously considered feasible, to market through rapid prototyping and deployment. Indeed, it has been reported that low-code and generative AI are accelerating innovation.[73]

6.3. Advanced technology at hand

Experts anticipate that human-level AI will be achievable before the turn of the century.[74] Without maintaining a forward-looking perspective when evaluating investment opportunities for innovative ideas, pharmaceutical businesses risk losing their market position to future visionaries who may disrupt the industry.

7. Conclusion

In the quest to advance science and improve public health, the utility of AI extends across the value chain (Figure 1), benefiting the clinical and commercial divisions of pharmaceutical businesses. While sensitive issues, such as data collection and analysis, require consideration, regulatory guidelines are in place to provide useful guardrails. Through pragmatism and collaboration, the pharmaceutical industry could shift the paradigm, embrace the new technological era, and leverage the full potential of AI to shape a better future for everyone.

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References

1. Toffler A. *Future Shock*. New York: Bantam Books; 1970.
2. Abed S. A literature review exploring the role of technology in business survival during the Covid-19 lockdowns. *Int J Organ Anal*. 2022;30(5):1045-1062.

   doi: 10.1108/IJOA-11-2020-2501
3. Zhu X, Ge S, Wang N. Digital transformation: A systematic literature review. *Comput Ind Eng*. 2021;162:107774.

doi: 10.1016/j.cie.2021.107774

4. Brodeur A, Gray D, Islam A, Bhuiyan S. A literature review of the economics of COVID-19. *J Econ Surv*. 2021;35(4):1007-1044.

   doi: 10.1111/joes.12423

5. Schwab K. The Fourth Industrial Revolution: what it means, how to respond1. In: *Handbook of Research on Strategic Leadership in the Fourth Industrial Revolution*. Edward Elgar Publishing; 2024:29-34.

   doi: 10.4337/9781802208818.00008

6. Russell S, Norvig P. *Artificial Intelligence: A Modern Approach*. 4th ed. London: Pearson; 2022.

7. Selvaraj C, Chandra I, Singh S. Artificial intelligence and machine learning approaches for drug design: Challenges and opportunities for the pharmaceutical industries. *Mol Divers*. 2021;26:1893-1913.

   doi: 10.1007/s11030-021-10326-z

8. Kulkov I. The role of artificial intelligence in business transformation: A case of pharmaceutical companies. *Technol Soc*. 2021;66:101629.

   doi: 10.1016/j.techsoc.2021.101629

9. Bodenheimer T, Sinsky C. From triple to quadruple aim: Care of the patient requires care of the provider. *Ann Fam Med*. 2014;12(6):573-576.

   doi: 10.1370/afm.1713

10. Kelly BS, Judge C, Bollard SM, *et al*. Radiology artificial intelligence: A systematic review and evaluation of methods (RAISE). *Eur Radiol*. 2022;32(11):7998-8007.

    doi: 10.1007/s00330-022-08784-6

11. Secinaro S, Calandra D, Secinaro A, Muthurangu V, Biancone P. The role of artificial intelligence in healthcare: A structured literature review. *BMC Med Inform Decis Mak*. 2021;21:125.

    doi: 10.1186/s12911-021-01488-9

12. Association of the British Pharmaceutical Industry. *Code of Practice for the Pharmaceutical Industry 2021*; 2021. Available from: https://www.abpi.org.uk/publications/code-of-practice-for-the-pharmaceutical-industry-2021 [Last accessed on 2023 May 01].

13. EY. *EY Smart Reviewer*; 2023. Available from: https://www.ey.com/en_uk/life-sciences/smart-reviewer [Last accessed on 2023 Jun 15].

14. Lucas S, Ailani J, Smith TR, Abdrabboh A, Xue F, Navetta MS. Pharmacovigilance: Reporting requirements throughout a product's lifecycle. *Ther Adv Drug Saf*. 2022;13:1-16.

    doi: 10.1177/20420986221125006

15. World Health Organization. *The Importance of Pharmacovigilance: Safety Monitoring of Medicinal Products*; 2002. Available from: https://www.who.int/publications/i/item/10665-42493 [Last accessed on 2023 Jun 18].

16. Salas M, Petracek J, Yalamanchili P, *et al*. The use of artificial intelligence in pharmacovigilance: A systematic review of the literature. *Pharmaceut Med*. 2022;36(5):295-306.

    doi: 10.1007/s40290-022-00441-z

17. Association of the British Pharmaceutical Industry. *Medicine Lifecycle*; 2021. Available from: https://www.abpi.org.uk/value-and-access/uk-medicine-pricing/medicine-lifecycle [Last accessed on 2023 Jun 24].

18. Tripathi A, Misra K, Dhanuka R, Singh JP. Artificial intelligence in accelerating drug discovery and development. *Recent Patents Biotech*. 2023;17(1):9-23.

    doi: 10.2174/1872208316666220802151129

19. Askin S, Burkhalter D, Calado G, El Dakrouni S. Artificial intelligence applied to clinical trials: Opportunities and challenges. *Health Technol* (*Berl*). 2023;13(2):203-213.

    doi: 10.1007/s12553-023-00738-2

20. Harrer S, Shah P, Antony B, Hu J. Artificial intelligence for clinical trial design. *Trends Pharmacol Sci*. 2019;40(8):577-591.

    doi: 10.1016/j.tips.2019.05.005

21. Hockings JK, Pasternak AL, Erwin AL, Mason N, Eng C, Hicks JK. Pharmacogenomics: An evolving clinical tool for precision medicine. *Cleve Clin J Med*. 2020;87(2):91-99.

    doi: 10.3949/ccjm.87a.19073

22. Capoot A, Constantino AK. Google Cloud Launches A.I.-Powered Tools to Accelerate Drug Discovery, Precision Medicine. *CNBC*. May 16, 2023. Available from: https://www.cnbc.com/2023/05/16/google-cloud-launches-ai-tools-to-accelerate-drug-discovery.html [Last accessed on 2023 Jun 13].

23. Euchner J. Generative AI. *Res Manage*. 2023;66(3):71-74.

    doi: 10.1080/08956308.2023.2188861

24. Ebert C, Louridas P. Generative AI for software practitioners. *IEEE Softw*. 2023;40(4):30-38.

    doi: 10.1109/MS.2023.3265877

25. McKinsey. *The Economic Potential of Generative AI: The Next Productivity Frontier*; 2023. Available from: https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-economic-potential-of-generative-ai-the-next-productivity-frontier [Last accessed on 2023 Jun 15].

26. Johnson A. Who's Winning the Chatbot Race? These Companies -from Meta to Alibaba -Have All Introduced AI-Powered Programs. *Forbes*. April 13, 2023. Available from: https://www.forbes.com/sites/ariannajohnson/2023/04/13/whos-winning-the-chatbot-race-these-companies--from-meta-to-alibaba-have-all-introduced-ai-powered-programs/ [Last accessed on 2023 Jun 13].

27. Rosario A, Moniz L, Cruz R. Data science applied to

marketing. *J Inform Sci Eng*. 2021;37(5):1067-1081.

doi: 10.6688/JISE.202109_37(5).0006

28. Verma S, Sharma R, Deb S, Maitra D. Artificial intelligence in marketing: Systematic review and future research direction. *Int J Inf Manag Data Insights*. 2021;1(1):100002.

doi: 10.1016/j.jjimei.2020.100002

29. Schoenherr T, Speier-Pero C. Data science, predictive analytics, and big data in supply chain management: Current state and future potential. *J Bus Logist*. 2015;36(1):120-132.

doi: 10.1111/jbl.12082

30. Huang Y. *Situation Awareness and Information Fusion in Sales and Customer Engagement: A Paradigm shift. IEEE Conference on Cognitive and Computational Aspects of Situation Management*; 2020. p. 113-121.

doi: 10.1109/CogSIMA49017.2020.9215990

31. Singh VL, Manrai AK, Manrai L. Sales training: A state of the art and contemporary review. *J Econ Finance Admin Sci*. 2015;20(38):54-71.

doi: 10.1016/j.jefas.2015.01.001

32. Luo X, Qin M, Fang Z, Qu Z. Artificial intelligence coaches for sales agents: Caveats and solutions. *J Mark*. 2021;85(2):14-32.

doi: 10.1177/0022242920956676

33. Roy M. Artificial intelligence in pharmaceutical sales & marketing-a conceptual overview. *Int J Innov Res Technol*. 2022;8(11):897-902.

34. Malthouse E, Copulsky J. Artificial intelligence ecosystems for marketing communications. *Int J Advert*. 2023;42(1):128-140.

doi: 10.1080/02650487.2022.2122249

35. Alkaissi H, McFarlane SI. Artificial hallucinations in ChatGPT: Implications in scientific writing. *Cureus*. 2023;15(2):e35179.

doi: 10.7759/cureus.35179

36. Anagnostou M, Karvounidou O, Katritzidaki C, *et al*. Characteristics and challenges in the industries towards responsible AI: A systematic literature review. *Ethics Inf Technol*. 2022;24(3):1-18.

doi: 10.1007/s10676-022-09634-1

37. Guembe B, Azeta A, Misra S, Osamor V, Fernandez-Sanz L, Pospelova V. The emerging threat of ai-driven cyber attacks: A review. *Appl Artif Intell*. 2022;36(1):1-34.

doi: 10.1080/08839514.2022.2037254

38. McKinsey & Company. *Four Ways Pharma Companies can make their Supply Chains More Resilient*; 2021. Available from: https://www.mckinsey.com/industries/life-sciences/our-insights/four-ways-pharma-companies-can-make-their-supply-chains-more-resilient [Last accessed on 2023 Jun 14].

39. Minh D, Wang H, Li Y, Nguyen T. Explainable artificial intelligence: A comprehensive review. *Artif Intell Rev*. 2022;55:1-66.

doi: 10.1007/s10462-021-10088-y

40. Information Commissioner's Office. *Consent*; 2018. Available from: https://ico.org.uk/for-organisations/uk-gdpr-guidance-and-resources/lawful-basis/a-guide-to-lawful-basis/lawful-basis-for-processing/consent [Last accessed on 2023 Jun 17].

41. Bostrom N. Existential risks: Analyzing human extinction scenarios and related hazards. *J Evol Technol*. 2002;9:1-30.

42. Li J, Huang J. Dimensions of artificial intelligence anxiety based on the integrated fear acquisition theory. *Technol Soc*. 2020;63:101410.

doi: 10.1016/j.techsoc.2020.101410

43. Griffin A. Facebook's Artificial Intelligence Robots Shut Down After they Start Talking to Each other in their Own Language. *The Independent*. September 10, 2020. Available from: https://www.independent.co.uk/life-style/facebook-artificial-intelligence-ai-chatbot-new-language-research-openai-google-a7869706.html [Last accessed on 2023 Jun 13].

44. The Google Engineer who Thinks the Company's AI has Come to Life. *The Washington Post*. June 11, 2022. Available from: https://www.washingtonpost.com/technology/2022/06/11/google-ai-lamda-blake-lemoine [Last accessed on 2023 Jun 13].

45. *National Artificial Intelligence Initiative: Overseeing and Implementing the United States National AI Strategy*; 2021. Available from: https://www.ai.gov [Last accessed on 2023 Jun 05].

46. US Chamber of Commerce. *Artificial Intelligence Commission Report*; 2023. Available from: https://www.uschamber.com/technology/artificial-intelligence-commission-report [Last accessed on 2023 Jun 22].

47. US Chamber of Commerce. *State-by-State Artificial Intelligence Legislation Tracker*; 2022. Available from: https://www.uschamber.com/technology/state-by-state-artificial-intelligence-legislation-tracker [Last accessed on 2023 Jul 16].

48. The White House. *Blueprint for an AI Bill of Rights: Making Automated Systems Work for the American People*; 2022. Available from: https://www.whitehouse.gov/ostp/ai-bill-of-rights [Last accessed on 2023 Jun 17].

49. National Institute of Standards and Technology. *AI Risk Management Framework*; 2023. Available from: https://www.nist.gov/itl/ai-risk-management-framework [Last accessed on 2032 Jun 23].

50. Europe has Fallen Behind America and the Gap is Growing. *Financial Times*. June 19, 2023. Available from: https://www.

ft.com/content/80ace07f-3acb-40cb-9 [Last accessed on 2023 Jun 19].

51. UK Government. *National AI Strategy*; 2021. Available from; https://www.gov.uk/government/publications/national-ai-strategy [Last accessed on 2023 Apr 29].

52. UK Government. *UK Unveils World Leading Approach to Innovation in First Artificial Intelligence White Paper to Turbocharge Growth*; 2023. Available from: https://www.gov.uk/government/news/uk-unveils-world-leading-approach-to-innovation-in-first-artificial-intelligence-white-paper-to-turbocharge-growth [Last accessed on 2023 Jun 21].

53. Information Commissioner's Office. *Artificial Intelligence*; 2022. Available from: https://ico.org.uk/for-organisations/uk-gdpr-guidance-and-resources/artificial-intelligence [Last accessed on 2023 Jun 13].

54. Roberts H, Babuta A, Morley J, Thomas C, Taddeo M, Floridi L. Artificial intelligence regulation in the United Kingdom: A path to good governance and global leadership? *Internet Policy Rev*. 2023;12(2):1-31.

doi: 10.14763/2023.2.1709

55. European Commission. *A European Approach to Artificial Intelligence*; 2023. Available from: https://digital-strategy.ec.europa.eu/en/policies/european-approach-artificial-intelligence [Last accessed on 2023 Jun 14].

56. European Parliament. *EU AI Act: First Regulation on Artificial Intelligence*; 2023. Available from: https://www.europarl.europa.eu/news/en/headlines/society/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence [Last accessed on 2023 Jun 14].

57. European Parliament. *The Artificial Intelligence Act*; 2023. Available from: https://artificialintelligenceact.eu [Last accessed on 2023 Jun 14].

58. European Companies Sound Alarm Over Draft AI Law. *Financial Times.* June 29, 2023. Available from: https://www.ft.com/content/9b72a5f4-a6d8-41aa-95b8-c75f0bc92465 [Last accessed on 2023 Jun 30].

59. International Coalition of Medicines Regulatory Authorities. *Horizon Scanning Assessment Report - Artificial Intelligence*; 2021. Available from: https://www.icmra.info/drupal/sites/default/files/2021-08/horizon_scanning_report_artificial_intelligence.pdf [Last accessed on 2023 Jun 21].

60. *Center for AI and Digital Policy. G7 and Artificial Intelligence*; 2023. Available from: https://www.caidp.org/resources/g7-japan-2023 [Last accessed on 2023 Jun 22].

61. Global Partnership on Artificial Intelligence. *GPAI/The Global Partnership on Artificial Intelligence*; 2023. Available from: https://gpai.ai [Last accessed on 2023 Jun 17].

62. Brennan C, Vlaev I, Blakemore M, Smith N. Consumer education and empowerment in Europe: Recent developments in policy and practice. *Int J Consum Stud*. 2017;41(2):147-157.

doi: 10.1111/ijcs.12322.

63. Equality and Human Rights Commission. *Protected Characteristics*; 2021. Available from: https://www.equalityhumanrights.com/en/equality-act/protected-characteristics [Last accessed on 2023 Jul 05].

64. UK Government Office for Science. *Innovation: Managing Risk, not Avoiding*; 2014. Available from: https://www.gov.uk/government/publications/innovation-managing-risk-not-avoiding-it [Last accessed on 2023 Jul 16].

65. Association of the British Pharmaceutical Industry. *How Skill Requirements are Changing*; 2023. Available from: https://www.abpi.org.uk/publications/how-skill-requirements-are-changing [Last accessed on 2023 Jun 10].

66. Harvard Business Review. *Your Company is Too Risk-Averse*; 2020. Available from: https://hbr.org/2020/03/your-company-is-too-risk-averse [Last accessed on 2023 Jul 13].

67. Rogers E. *Diffusion of Innovations*. London: Collier-Macmillan; 1962.

68. Durao F, Carvalho J, Fonseka A, Garcia V. A systematic review on cloud computing. *J Supercomput*. 2014;68:1321-1346.

doi: 10.1007/s11227-014-1089-x

69. Solenov D, Brieler J, Scherrer J. The potential of quantum computing and machine learning to advance clinical research and change the practice of medicine. *Mo Med*. 2018;115(5):463-467.

70. Soeparno H, Perbangsa A. Cloud quantum computing concept and development: A systematic literature review. *Procedia Comput Sci*. 2021;179:944-954.

doi: 10.1016/j.procs.2021.01.084

71. Tyagi AK, ed. Handbook of Research on Quantum Computing for Smart Environments. *Advances in Systems Analysis, Software Engineering, and High Performance Computing*; 2023.

doi: 10.4018/978-1-6684-6697-1

72. Binzer B, Winkler T. Democratizing software development: A systematic multivocal literature review and research agenda on citizen development. *Int Conf Softw Bus*. 2022;463:244-259.

doi: 10.1007/978-3-031-20706-8_17

73. Curry R. How Generative A.I. and Low-Code are Speeding up Innovation. *CNBC*. May 19, 2023. Available from: https://www.cnbc.com/2023/05/19/generative-ai-and-low-code-are-speeding-up-innovation.html [Last accessed on 2023 May 20].

74. World Economic Forum. *Here's how Experts See AI Developing Over the Coming Years*; 2023. Available from: https://www.weforum.org/agenda/2023/02/experts-ai-developing-over-the-coming-years [Last accessed on 2023 Jun 08].