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Biotechnology and artificial intelligence integration: A concise review of advanced application, advantages and challenges in healthcare

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Abstract

Everyone is talking about artificial intelligence (AI) these days. Unprecedented new potential solutions are made possible when biotechnology and artificial intelligence breakthroughs are coupled. This can support significant Sustainable Development Goals and assist with a number of global issues. Food security, health and well-being sustainable energy, conscientious production and consumption, climate action, and life below water, safeguarding, restoring, and promoting the environmentally friendly forest management and the sustainable utilization of terrestrial ecosystems, preventing desertification, stopping and going backwards degradation, and stopping biodiversity loss are a few instances that are presently in the news. The biological sciences are now heavily reliant on artificial intelligence. Recent advances in artificial intelligence (AI) and biotechnology have brought about a convergence that could completely transform the healthcare industry. This review investigates the benefits and challenges of biotechnology in the healthcare industry by providing up-to-date case studies on its applications.

Keywords: Artificial intelligence; Biotechnology; Global issues; Health

1. Introduction

1.1. Present-Day Biotechnology for Pharmaceutical Issues and AI's Role

Pharmaceutical innovation is led by biotechnology, especially in fields like medication research, personalized medicine, and biologics manufacturing.Advances in protein engineering, genetic engineering, and cell culture technology are making complex medicinal solutions possible [1].Because of their many benefits, the pharmaceutical industry is constantly researching tiny molecules to provide better products and increase customer happiness. While the preparation of synthetic derivatives is cost-effective, the chemical synthesis process is straightforward.

Therefore, the pharmacy industry has a wide variety of stable and effective small-molecule-loaded formulations. With the exception of rare disease treatments, generic molecules compete with numerous novel small molecules, and their introduction necessitates complicated data and clinical trials. These procedures put more financial pressure on businesses to innovate more. To make up for the problem brought on by the small molecular size and inadequate dispersion, the biomolecular medication business is nevertheless expanding quickly.[2,3,4,5,6,7,8]

Large units called biomolecules are primarily composed of nucleotides or ribonucleotides for the nucleic acid and amino acids from the protein source. The spatial conformation and supramolecular sequence also affect their stability and function [9]. Adalimumab and insulin are two examples of biomolecules that have achieved great success. Since infusion is the most practical and preferred method of administering these macromolecules, their pharmacokinetic

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characteristics are complicated. Important facets of nucleic acid-based research include molecular stability and pharmacokinetic regulation. Enhancement and pharmacokinetic exposure of these molecular forms are important objectives. To overcome these obstacles and resolve associated problems, new technical developments could be beneficial [10,11,12,13,14,15]. Despite the fact that AI holds great promise for enhancing the delivery and discovery of medicines.

1.2. Energizing Biotech's Future: An Examination of AI Networks and Tools

Artificial intelligence (AI) has had a significant and transformative impact on biotechnology, upgrading conventional methods and opening up new avenues for commercial applications, medical and wellness research, and scientificinvestigation.Researchers are making unthinkable strides by combining the biological sciences with sophistic ated computation.Traditional biotechnology techniques have been greatly altered by AI and machine learning (ML) in a number of fields. These key biotechnology disciplines are some of the most signifd transformative impact on biotechnology, upgrading conventional methods and opening up new avenues for research in science, health and medicine, and industry. Through the integration of advanced computation and biological sciences, scientists are achieving previously unimaginable breakthroughs. Artificial intelligence (AI) and machine learning (ML) have significantly influenced traditional biotechnology methods in a wide range of domains.Artificial Intelligence has significantly impacted biotechnology in the following key areas.[16]

AI comprises a wide range of methodologies, including reasoning, knowledge representation, and solution search, with machine learning (ML) serving as a central paradigm. Deep learning [DL] is a subset of machine learning that uses artificial neural networks [ANNs] to mimic the complexity of human neurons, capturing the core of how our brains receive and transfer information. The table below summarizes several significant AI technologies and techniques that are altering the area of biotechnology.[17]

2. Interlocking difficulties

2.1. A. Assisting in the creation of a trustworthy AI model

In recent decades, reproducibility problems have plagued biotechnological and biomedical research.[18,19,20,21,22,23,24] Studies that systematically examine the causes of these issues. [25] Demonstrate that they are not limited to a single area but rather occur in different parts of the entire chains of research objects, from biological material to data generated/collected to data processing/analysis. The creation of AI models is a particular kind of data processing that has unique reproducibility difficulties.[26]

It is widely acknowledged that thorough documentation of research objects and their chains can significantly improve the traceability, reproducibility, and reliability of research findings. Several fields within the biotechnology and life sciences are working to improve the current state of affairs.[27,28,29] , As a result, the provenance model was created [30] which, in dispersed multi-institutional settings, provide the machine-readable documentation of research objects' histories. [31]including the 23494 standard series, which is an ISO standard development. Domain-specific model extensions can be utilized for programmatic evaluation of data quality, or fitness for certain applications ,when they become available and provenance is generated in a systematic manner. Many regulatory goals, including gain access to and advantages of In exchange for genetic resources (ABS, commonly referred to as the Nagoya protocol), can additionally be supported by machine-readable provenance.[32,33] or records needed to comply with clinical trials or the In Vitro Diagnostic Regulations (IVDR)[34]. The availability of significant amounts of data that fit the purpose for which they were designed, that is , of acceptable quality, is the main constraint on the creation of AI models. In many instances, the availability of biological material that is appropriate for its intended purpose. determines the availability of the data. The widespread use of FAIR principles has encouraged data availability generally has been sparked by the widespread acceptance of FAIR principles [35]and its thematic or domain extensions, as FAIR4RS or FAIR-Health[36] .The availability of software and the reproducibility of its runs are additional factors unique to the development of AI models. While use of public repositories like GitHub or BitBucket, as their use of AI frameworks1 and model creation, has significantly increased code availability, It's possible that the AI models themselves weren't trained in a repeatable manner. Recently, strategies for their deterministic operation have been developed in response to these repeatability problems.

2.2. Comprehending ai methodologies

Explainability, along with robustness, is crucial for trustworthiness in AI solutions[37,38] Explainability in biotechnology helps researchers, policymakers, and stakeholders align AI decisions with their values and aims. AI systems in biotechnology evaluate vast volumes of data and generate predictions that impact public health, environmental safety, and other areas. Uncertainty about the accuracy and dependability of an AI system's outputs can arise if it lacks clear

explanations for its decisions and predictions. Explainability building trust and identifying potential biases .Understanding how and why an AI system makes judgments that are damaging to particular populations is crucial for taking appropriate corrective action. An AI developer can ensure that distinct things Stakeholders can grasp how an AI model works in general and for specific data scenarios. Effective solutions include:

- Clear documentation and explanations of AI model architecture and training. This can give interested parties with insight into the model's design and intended functionality.
- Using interpretable models [39]or, if that is not possible, use interpretability techniques. Explainable AI approaches can improve the interpretability of AI models[40]
- Use graphical representations [41]to describe the model's outputs and decision-making process, assisting stakeholders in understanding how it arrived at a conclusion[42] .

Respond to stakeholder queries and concerns to assist them understand the model. This may require offering further explanations or demonstrating the model's functionality. To determine the boundary conditions for an AI model's statistical performance, it's crucial to test its performance across various settings and data sets[43] .Experiments and simulations can be used to test the model's performance in different settings and compare it to other algorithms or baselines. Consider the model's robustness, generalizability, and any biases or restrictions in data or analysis. Evaluating the model's performance under various settings might reveal the optimal conditions for achieving a certain degree of statistical performance.

Explainability is crucial for the trustworthiness and ethical use of AI in biotechnology. It enables humans to understand and assess decision-making processes, assuring responsible and beneficial application. It is critical for AI developers to be proactive in engaging with stakeholders and providing them with the knowledge and tools they require to understand how the AI model functions and how it is used.

Explainability is crucial for data quality and compliance with the In Vitro Diagnostic Regulation (IVDR). It helps stakeholders understand how data was acquired and used. The IVDR uses data to ensure the safety, performance, and clinical relevance of IVD medical devices. Using low-quality or inappropriate data to support claims can jeopardize patient safety. The performance and clinical significance of in vitro diagnostic (IVD) medical equipment. Inaccurate or low-quality data used to support claims can harm patient safety and diagnostic accuracy [44]. Explainability is crucial for data quality as it helps stakeholders understand how it was acquired and if it is representative of the intended population. Stakeholders can comprehend the appropriate use of data to support claims about IVD medical devices. Explainability is crucial in IVDR to ensure reliable data for safety, performance, and clinical relevance IVD medical devices are of high quality and handled responsibly. The IVDR requires visible, traceable, and verifiable evidence to support claims, with explainability being a significant aspect in meeting these requirements. Clear explanations of data collection, use, and claims can increase stakeholder confidence in the safety, performance, and clinical relevance of IVD medical devices.

2.3. Interfaces between humans and ai

The success of any AI application in the biotechnology sector depends on human-AI interfaces because they facilitate efficient and natural communication between humans and AI systems while promoting explainability and causability[45]. Before anything is put into action, rapid prototyping including all stakeholders can be very beneficial [46,47] The secret is user-centered design (UCD)[48] which has been shown to provide high-quality AI solutions and good usability while also satisfying end users in biotechnology, who are largely not computer geeks. The human-in-the-loop technique, which involves putting people directly in the AI pipeline, is a relatively recent strategy[49] Integrating human input and advise into the development and operation of AI algorithms is referred to as the human-in-the-loop (HITL) approach. The goal of HITL is to enable effective and efficient collaboration between humans and AI systems to achieve common goals. Artificial intelligence algorithms can be developed using the HITL principle in a number of ways. As an example:

- Human oversight: in this method, humans participate in the creation and management of the AI algorithm, offering supervision and direction to guarantee that the algorithm is operating as planned.
- Human feedback: with this method, people contribute to the creation and functioning of the AI system by giving it advice and comments while it learns and makes judgments.
- Human-AI collaboration: with this strategy, people and AI systems cooperate as equals, utilizing their complementary skills and strengths to accomplish shared objectives.

2.4. AI morality,equity and reliability

Lastly, it is undeniable that research on AI ethics[50] justice and trust is crucial to the use of AI in biotechnology. Examples of (open) research questions include:

- How can we guarantee that AI systems are fair and do not reinforce or magnify preexisting biases or discrimination?
- How can we guarantee that AI systems are developed and applied in ways that are morally and socially responsible, respecting fundamental human rights and values?
- How can we guarantee that AI systems are understandable and transparent so that stakeholders and users may have faith in them?[51]
- AI/ML and data analytics: Due to their ability to evaluate vast information and forecast intricate biological systems, they are becoming more and more significant in the field of biotechnology. This includes analyzing proteomic and genomic data using AI approaches., all sorts of *omics and many other types of biological data to better understand the underlying mechanisms of diseases and to identify potential therapeutic targets.
- Drug discovery and development: AI can be used to analyze large amounts of data to identify patterns and relationships that may not be apparent to humans. This can be used to help identify new drugs and drug targets, as well as to optimize existing therapies.[52]

3. Biotechnology and Artificial Intelligence Converging

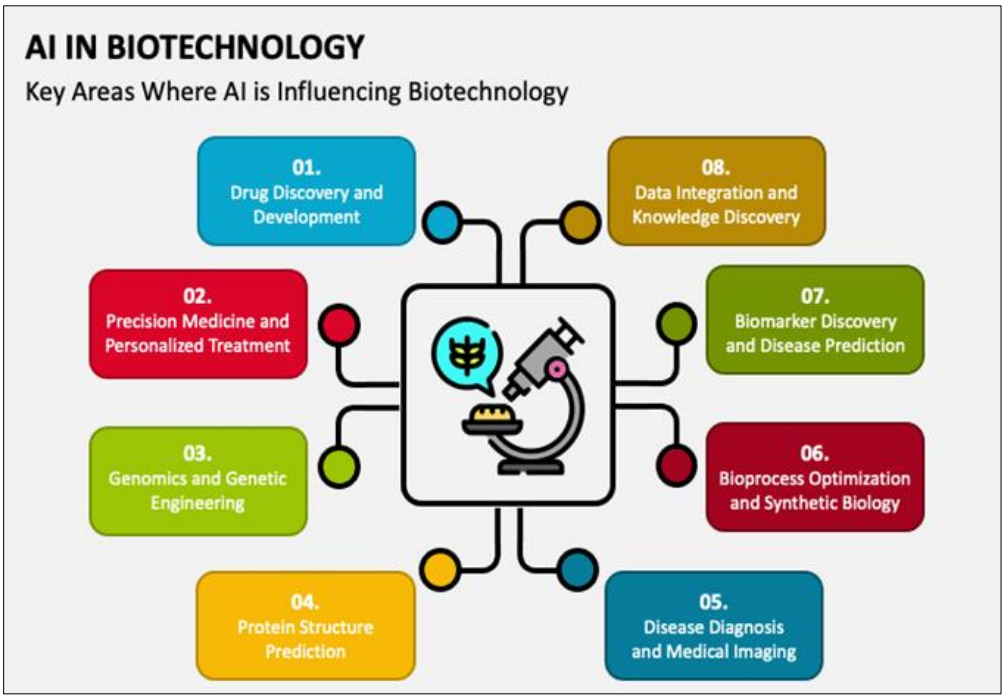

Figure 1 AI Influencing biotechnology

The combination of biotechnology and artificial intelligence has ushered in a new era of innovation and exploration. Combining AI and biotechnological methods allows researchers to better understand and address complicated biological issues. Since genomics evaluates vast amounts of genetic data using AI techniques like machine learning and deep learning, it is a notable example of this convergence. Scientists can find patterns and connections in DNA sequences by comprehending how genes interact and contribute to various characteristics and diseases. Thus, AI-powered genomics research may speed up the development of customized therapies and targeted treatments [53] Drug discovery is one instance where the two fields collide. Systems using artificial intelligence are able to analyze massive databases. Compared to human experts, Much faster and more precise analysis of large databases of chemical substances and biological targets is possible with artificial intelligence systems. Using AI in drug development[54] potentially help researchers save time and money while raising the chances of finding successful therapies for a range of ailments. Artificial intelligence (AI) and biotechnology have also advanced synthetic biology, allowing scientists to create new biological systems that are well-suited to perform specific tasks. By anticipating how changes to DNA will affect the functionality of organisms or their components, artificial intelligence could aid in the design process[55.] This makes it

possible to create biofuels, biodegradable polymers, and more accurate and efficient tailored medicine delivery systems than their predecessors. Finally, combining biotechnology with AI AI in research has the potential to revolutionize a variety of fields, including ecology, energy, medicine, and agriculture. Scientists may uncover important worldwide concerns and create innovative solutions by employing AI to interpret complex biological data.[56,57,58,59,60]

3.1. The Prospects of Artificial Intelligence in Biotechnology

The healthcare sector stands to gain a great deal from the combination of biotechnology and AI in several ways. The future directions and ramifications of this convergence in healthcare will be covered in this section, which focuses on crucial subjects including precision medicine, medication development, diagnostics, and ethics.[61]

- **Biotechnology and Ethical AI:** The adoption and efficacy of AI systems in healthcare and genetics will depend on their transparency, interpretability, and lack of prejudice.[62]
- **Regulation of Biotechnology Products:** As AI makes it possible for more complex genetic alterations, regulatory agencies such as the FDA and EMA will have to create new guidelines for the authorization and oversight of biotech products powered by AI.[63]

3.2. An Examination of AI and Biotechnology Case Studies in the Healthcare Sector

Improvements in biotechnology and artificial intelligence (AI) have made it feasible to detect illnesses more precisely and create customized treatment regimens[64] Telemedicine, genomics, imaging, and drug discovery are just a few of the medical domains that have advanced significantly as a result of combining these two professions. [65]. AI-powered systems that are used to diagnose illnesses may evaluate images from medical tests such as CT, MRI, and X-rays[66]. For example, deep learning algorithms trained to identify patterns in medical images may be used to diagnose cancer, Alzheimer's, and heart disease sooner[67]. Only because of biotechnology's contribution to medicine are molecular diagnostic tools like next-generation sequencing (NGS) and polymerase chain reaction (PCR) available. Finding the distinct genetic component of a disease. In order to find customized treatments, the healthcare sector uses artificial intelligence (AI) algorithms to sort through massive amounts of patient and genomic data. This enables physicians to tailor therapy to each patient, increasing treatment success and lowering side effects[68].

4. Opportunities for the Future and Improvements

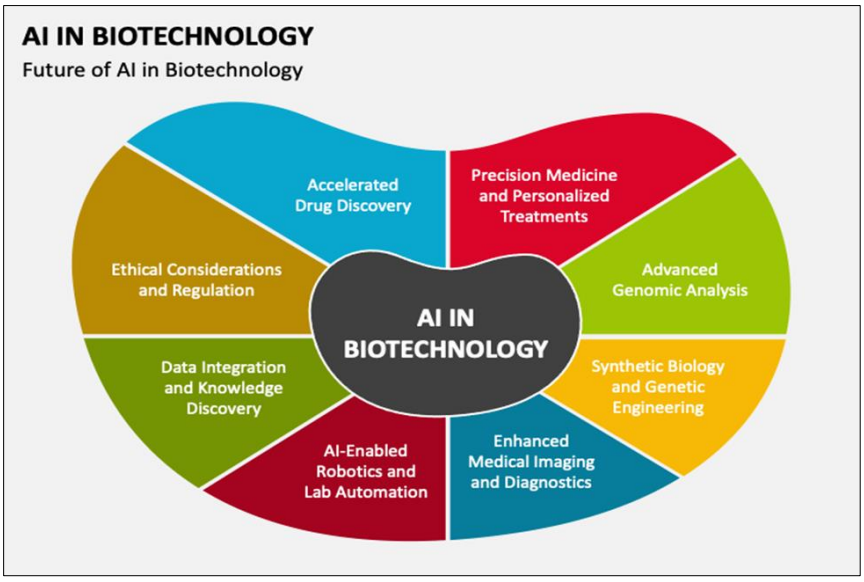

Figure 2 Future of ai in biotechnology

In order for the Biotechnology-AI Nexus to realize its full potential, we must overcome its challenges, among these is the requirements for interdisciplinary collaboration, concerns about data security and privacy, moral conundrums, regulatory compliance, and others. In order to allay these worries, scientists, medical professionals, policymakers, and business representatives should work together to create an atmosphere that encourages responsible innovation and guarantees a fair distribution of the benefits[69]. Another worry brought on by the potential for automation and artificial intelligence to alter the character of the labor market is worker displacement[70]. Investments in re skilling and up skilling

are required to guarantee that healthcare personnel have the skills to adapt to technological advancements as biotechnology in AI.[71]

5. Conclusion

AI is a very vague word that is used today to refer to almost anything that involves the processing of data by a digital information processing system. Therefore, digitization and digital transformation are essential to the start of any AI application. The essential drivers have been and will remain the rapid development in processing power and the availability of vast and high-quality data volumes. These will remain AI's primary motivators going forward. As of right now, there is no end in sight to this development process, which is still ongoing. Although the media and professional futurologists' depictions of the future will differ, it is very probable that artificial intelligence will play a bigger role in biotechnology.

This review has covered AI in healthcare as well as a few case examples of advanced applications. A future in which the complementary strengths of biotechnology and artificial intelligence are used to enhance healthcare quality, efficiency, and accessibility for all is made possible by regularly compiling these discoveries. This article examines a number of cutting-edge application case studies that use AI to promote biotechnology.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed

References

[1] Doudna JA, Charpentier E. The new frontier of genome engineering with CRISPR-Cas9. Science. 2014 Nov 28;346(6213):1258096.

[2] Dickherber A, Morris SA, Grodzinski P. NCI investment in nanotechnology: achievements and challenges for the future. Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology. 2015 May;7(3):251-65.

[3] Roco MC. The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years. Journal of Nanoparticle Research. 2011 Feb; 13:427-45.

[4] Colombo S, Beck-Broichsitter M, Bøtker JP, Malmsten M, Rantanen J, Bohr A. Transforming nanomedicine manufacturing toward Quality by Design and microfluidics. Advanced drug delivery reviews. 2018 Mar 15; 128:115-31.

[5] Troiano G, Nolan J, Parsons D, Van Geen Hoven C, Zale S. A quality by design approach to developing and manufacturing polymeric nanoparticle drug products. The AAPS journal. 2016 Nov;18(6):1354-6

[6] Al-Zahrani MM. Generational Advancements in the Transverse Shear Strength Retention of Glass Fiber-Reinforced Polymer Bars in Alkaline and Acidic Environments. Polymers. 2024 Sep 25;16(19):2712.

[7] Suriyaamporn P, Pamornpathomkul B, Patrojanasophon P, Ngawhirunpat T, Rojanarata T, Opanasopit P. The Artificial Intelligence-Powered New Era in Pharmaceutical Research and Development: A Review. AAPS PharmSciTech. 2024 Aug 15;25(6):188.

[8] Ali KA, Mohin SK, Mondal P, Goswami S, Ghosh S, Choudhuri S. Influence of artificial intelligence in modern pharmaceutical formulation and drug development. Future Journal of Pharmaceutical Sciences. 2024 Mar 29;10(1):53.

[9] Chavda VP, Anand K, Apostolopoulos V, editors. Bioinformatics Tools for Pharmaceutical Drug Product Development. John Wiley & Sons; 2023 Feb 9.

[10] Ali KA, Mohin SK, Mondal P, Goswami S, Ghosh S, Choudhuri S. Influence of artificial intelligence in modern pharmaceutical formulation and drug development. Future Journal of Pharmaceutical Sciences. 2024 Mar 29;10(1):53.

[11] Li Y, Liao Y, Sun Z, Liu X. Semi-supervised contrastive regression for pharmaceutical processes. Expert Systems with Applications. 2024 Mar 15; 238:121974.

[12] Bentele R, Weder R. On the importance of Swiss patient data for pharmaceutical R&D in Switzerland. WWZ Working Paper; 2024.

[13] Taylor D, Bowden SG, Knorr R, Wilson DR, Proudfoot J, Dunlop AE. The Pistoia alliance controlled substance compliance service project: from start to finish. Drug Discovery Today. 2015 Feb 1;20(2):175-80.

[14] Lee CK, Choy KL, Chan YN. A knowledge-based ingredient formulation system for chemical product development in the personal care industry. Computers & chemical engineering. 2014 Jun 4; 65:40-53.

[15] Shang S, Shi Y, Zhang Y, Liu M, Zhang H, Wang P, Zhuang L. Artificial intelligence for brain disease diagnosis using electroencephalogram signals. Journal of Zhejiang University-SCIENCE B. 2024 Oct;25(10):914-40.

[16] Nunavath RS, Nagappan K. Future of Pharmaceutical Industry: Role of Artificial Intelligence, Automation and Robotics. Journal of Pharmacology & Pharmacotherapeutics. 2024 Jun 1;15(2).

[17] Ali M, Shabbir K, Ali S, Mohsin M, Kumar A, Aziz M, Zubair M, Sultan HM. A New Era of Discovery: How Artificial Intelligence has Revolutionized the Biotechnology. Nepal Journal of Biotechnology. 2024 Jul 31;12(1):1-1.

[18] Lohse S. Questionable Research Practices and the Reproducibility Crisis in Animal-Based Biomedicine: A New Perspective.

[19] Servick K, Enserink M. The pandemic's first major research scandal erupts.

[20] Lagoze C. Big Data, data integrity, and the fracturing of the control zone. Big Data & Society. 2014 Nov 11;1(2):2053951714558281.

[21] Mobley A, Linder SK, Braeuer R, Ellis LM, Zwelling L. A survey on data reproducibility in cancer research provides insights into our limited ability to translate findings from the laboratory to the clinic. PloS one. 2013 May 15;8(5):e63221

[22] Morrison SJ. Time to do something about reproducibility. Elife. 2014 Dec 10;3:e03981.

[23] Byrne JA, Grima N, Capes-Davis A, Labbé C. The possibility of systematic research fraud targeting under-studied human genes: causes, consequences, and potential solutions. Biomarker Insights. 2019 Feb; 14:1177271919829162.

[24] Stoten A, Kröger AC, Draper M, Reinhard F, Hanke T. From academic concept to commercial reality: How to accelerate trans lational drug discovery.

[25] Freedman LP, Inglese J. The increasing urgency for standards in basic biologic research. Cancer research. 2014 Aug 1;74(15):4024-9..

[26] Kodetzki M, Bordis T, Kirsten M, Schaefer I. Towards AI-assisted correctness-by-construction software development. InInternational Symposium on Leveraging Applications of Formal Methods 2024 Oct 26 (pp. 222-241). Cham: Springer Nature Switzerland.

[27] Sweileh WM. Research landscape analysis on dual diagnosis of substance use and mental health disorders: key contributors, research hotspots, and emerging research topics. Annals of General Psychiatry. 2024 Aug 30;23(1):32.

[28] Dagli N, Haque M, Kumar S. The Replication Crisis: A Persistent Challenge in Biomedical Research. Bangladesh Journal of Medical Science. 2024 Oct 2;23(4):907-10.

[29] Landis SC, Amara SG, Asadullah K, Austin CP, Blumenstein R, Bradley EW, Crystal RG, Darnell RB, Ferrante RJ, Fillit H, Finkelstein R. A call for transparent reporting to optimize the predictive value of preclinical research. Nature. 2012 Oct 11;490(7419):187-91..

[30] Gierend K, Krüger F, Genehr S, Hartmann F, Siegel F, Waltemath D, Ganslandt T, Zeleke AA. Provenance Information for Biomedical Data and Workflows: Scoping Review. Journal of Medical Internet Research. 2024 Aug 23;26:e51297.

[31] de Zegher I, Norak K, Steiger D, Müller H, Kalra D, Scheenstra B, Cina I, Schulz S, Uma K, Kalendralis P, Lotman EM. Artificial intelligence based data curation: enabling a patient-centric European health data space. Frontiers in medicine. 2024 May 15; 11:1365501.

[32] Martins JE, da Cruz Freire JE, Vasconcelos-Filho FS, da Silva de Almeida D, Ceccatto VM, de Sousa BL. Computational Insights into the Interaction between Neprilysin and α-Bisabolol: Proteolytic Activity against Beta-Amyloid Aggregates in Alzheimer's Disease. Processes. 2024 Apr 27;12(5):885.

[33] Holzinger A, Keiblinger K, Holub P, Zatloukal K, Müller H. AI for life: Trends in artificial intelligence for biotechnology. New Biotechnology. 2023 May 25; 74:16-24.

[34] Diaw MD, Papelier S, Durand-Salmon A, Felblinger J, Oster J. AI-assisted QT measurements for highly automated drug safety studies. IEEE Transactions on Biomedical Engineering. 2022 Nov 10;70(5):1504-15.

[35] Cannata C, Vidaurre R, Ragas AM, Moermond CT. A database on pharmaceuticals in the environment: What do stakeholders need?. Environmental Science & Policy. 2024 Dec 1; 162:103946.

[36] Soltero RG, García DP, Bellido A, Ryan P, Rodríguez-Learte AI. FAIR data management: a framework for fostering data literacy in biomedical sciences education. BMC Medical Research Methodology. 2024 Nov 16; 24:284.

[37] Holzinger A. Biomedical informatics. Books on Demand; 2012.

[38] Alizadehsani R, Oyelere SS, Hussain S, Jagatheesaperumal SK, Calixto RR, Rahouti M, Roshanzamir M, De Albuquerque VH. Explainable artificial intelligence for drug discovery and development-a comprehensive survey. IEEE Access. 2024 Mar 4.

[39] Rudin M, Sauter A. In vivo NMR in pharmaceutical research. Magnetic resonance imaging. 1992 Jan 1;10(5):723-31.

[40] Holzinger A, Saranti A, Molnar C, Biecek P, Samek W. Explainable AI methods-a brief overview. InInternational workshop on extending explainable AI beyond deep models and classifiers 2022 (pp. 13-38). Springer, Cham.

[41] Müller H, Reihs R, Zatloukal K, Holzinger A. Analysis of biomedical data with multilevel glyphs. BMC bioinformatics. 2014 May; 15:1-2.

[42] Hund M, Böhm D, Sturm W, Sedlmair M, Schreck T, Ullrich T, Keim DA, Majnaric L, Holzinger A. Visual analytics for concept exploration in subspaces of patient groups: making sense of complex datasets with the doctor-in-the-loop. Brain Informatics. 2016 Dec; 3:233-47.

[43] Soriano-Gonzalez R, Tsertsvadze V, Osorio C, Fuster N, Juan AA, Perez-Bernabeu E. Balancing Risk and Profit: Predicting the Performance of Potential New Customers in the Insurance Industry. Information. 2024 Sep 6;15(9):546.

[44] Reniewicz J, Suryaprakash V, Kowalczyk J, Blacha A, Kostello G, Tan H, Wang Y, Reineke P, Manissero D. Artificial intelligence/machine-learning tool for post-market surveillance of in vitro diagnostic assays. New Biotechnology. 2024 Mar 25;79:82-90.

[45] Desolda G, Dimauro G, Esposito A, Lanzilotti R, Matera M, Zancanaro M. A Human–AI interaction paradigm and its application to rhinocytology. Artificial Intelligence In Medicine. 2024 Sep 1; 155:102933.

[46] Sjømæling TL, Finstad HJ. Efficient Data Visualization in Healthcare: A User-Friendly Sepsis Dashboard for Clinicians (Master's thesis, NTNU).

[47] Vankadaru V, Penugonda G, Parvathaneni NS, Bhoi AK. Heart Failure Prediction Using Radial Basis with Metaheuristic Optimization. InEnabling Person-Centric Healthcare Using Ambient Assistive Technology: Personalized and Patient-Centric Healthcare Services in AAT 2023 Sep 2 (pp. 129-150). Cham: Springer Nature Switzerland.

[48] Hussain Z, Slany W, Holzinger A. Current state of agile user-centered design: A survey. InHCI and Usability for e-Inclusion: 5th Symposium of the Workgroup Human-Computer Interaction and Usability Engineering of the Austrian Computer Society, USAB 2009, Linz, Austria, November 9-10, 2009 Proceedings 5 2009 (pp. 416-427). Springer Berlin Heidelberg.

[49] Tapia EC, Infantes JJ, Calderón PC, Mendoza GM, Jiménez HR, Girón EC. Health and medical informatics research: Identifying international collaboration patterns at the country and institution level. Iberoamerican Journal of Science Measurement and Communication. 2024 Oct 31;4(3):1-6.

[50] Zhiganova LP. MODERN TRENDS IN ARTIFICIAL INTELLIGENCE FOR BIOTECHNOLOGY.

[51] Hoenigsberger F, Saranti A, Jalali A, Stampfer K, Holzinger A. Explainable Artificial Intelligence to Support Work Safety in Forestry: Insights from Two Large Datasets, Open Challenges, and Future Work. Applied Sciences. 2024 May 3;14(9):3911.

[52] Bridges KE. Human and artificial intelligence considerations for long duration space travel–A human factors perspective. Journal of Space Safety Engineering. 2023 Dec 1;10(4):433-8.

[53] Abdullah M. Integrating Artificial Intelligence in Precision Medicine: Enhancing Predictive Accuracy and Personalized Care in Chronic Disease Management. Medical and Life Sciences. 2024 Jun 23;3(1):6-15.

[54] Suriyaamporn P, Pamornpathomkul B, Patrojanasophon P, Ngawhirunpat T, Rojanarata T, Opanasopit P. The Artificial Intelligence-Powered New Era in Pharmaceutical Research and Development: A Review. AAPS PharmSciTech. 2024 Aug 15;25(6):188.

[55] MuzamalHussain N, Afzal M, Ullah O, Raheem MA. Biotechnology-Artificial Intelligence Nexus: A Mini Review of Advanced Applications, Benefits, and Challenges in the Healthcare Domain. Biotechnology. 2024 Jan;7(1):185-200.

[56] Liang X, Brainerd B, Hicks T, Andris C. Lessons from a human-in-the-loop machine learning approach for identifying vacant, abandoned, and deteriorated properties in Savannah, Georgia. Journal of Planning Education and Research. 2024 Aug 31:0739456X241273945.

[57] Holzinger A, Keiblinger K, Holub P, Zatloukal K, Müller H. AI for life: Trends in artificial intelligence for biotechnology. New Biotechnology. 2023 May 25;74:16-24.

[58] Rujano MA, Boiten JW, Ohmann C, Canham S, Contrino S, David R, Ewbank J, Filippone C, Connellan C, Custers I, van Nuland R. Sharing sensitive data in life sciences: an overview of centralized and federated approaches. Briefings in Bioinformatics. 2024 May 23;25(4).

[59] Ali M, Shabbir K, Ali S, Mohsin M, Kumar A, Aziz M, Zubair M, Sultan HM. A New Era of Discovery: How Artificial Intelligence has Revolutionized the Biotechnology. Nepal Journal of Biotechnology. 2024 Jul 31;12(1):1-1.

[60] Holzinger A, Dehmer M, Emmert-Streib F, Cucchiara R, Augenstein I, Del Ser J, Samek W, Jurisica I, Díaz-Rodríguez N. Information fusion as an integrative cross-cutting enabler to achieve robust, explainable, and trustworthy medical artificial intelligence. Information Fusion. 2022 Mar 1; 79:263-78..

[61] Haleem A, Javaid M. Role of cognitive computing in enhancing innovative healthcare solutions. Advances in Biomarker Sciences and Technology. 2024 Jan 1; 6:152-65.

[62] Rashed Khan M. Application of Artificial Intelligence for Talent Management: Challenges and Opportunities.

[63] Petrini, C., et al. (2022). "Ethics of artificial intelligence in biotechnology." Frontiers in Genetics, 13, 123.

[64] MuzamalHussain N, Afzal M, Ullah O, Raheem MA. Biotechnology-Artificial Intelligence Nexus: A Mini Review of Advanced Applications, Benefits, and Challenges in the Healthcare Domain. Biotechnology. 2024 Jan;7(1):185-200.

[65] MuzamalHussain N, Afzal M, Ullah O, Raheem MA. Biotechnology-Artificial Intelligence Nexus: A Mini Review of Advanced Applications, Benefits, and Challenges in the Healthcare Domain. Biotechnology. 2024 Jan;7(1):185-200.

[66] Singh P, Singh N, Singh KK, Singh A. Diagnosing of disease using machine learning. InMachine learning and the internet of medical things in healthcare 2021 Jan 1 (pp. 89-111). Academic Press.

[67] Kaur D, Singh B, Rani S. Machine Learning for Internet of Medical Things Applications: Framework, Developments, and Challenges. InEvolution of Machine Learning and Internet of Things Applications in Biomedical Engineering 2025 (pp. 18-40). CRC Press..

[68] Waden J. Artificial intelligence and its role in the development of personalized medicine and drug control. Wasit J Comput Math Sci. 2022;1(4):126-33.

[69] Tariq MU, editor. AI-Driven Learning and Engagement in Higher Education. IGI Global; 2024 Sep 25.

[70] MuzamalHussain N, Afzal M, Ullah O, Raheem MA. Biotechnology-Artificial Intelligence Nexus: A Mini Review of Advanced Applications, Benefits, and Challenges in the Healthcare Domain. Biotechnology. 2024 Jan;7(1):185-200.

[71] Ahmed MN, Toor AS, O'Neil K, Friedland D. Cognitive computing and the future of health care cognitive computing and the future of healthcare: the cognitive power of IBM Watson has the potential to transform global personalized medicine. IEEE pulse. 2017 May 16;8(3):4-9.