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Impact of Metaverse Technologies Integration on Biotechno-logical Innovation: A Literature Review

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Abstract

The convergence of metaverse technologies (such as virtual reality, augmented reality, artificial intelli-gence, and digital twins) into biotechnology is ushering in a new age for the creation of pharmaceuticals, medical science research, and teaching. The interactive and immersive environments enable collaboration without geographical limitations through virtual labs, improve the articulation of complex biological processes, and accelerate experiments using enhanced models powered by artificial intelligence. High-visibility use cases comprise virtual clinical trials founded on digital twin models that simulate individual patient profiles. The application of AI in drug discovery medicine, with its expedited time-to-market and 3D learning environments, enhances the knowledge and procedural precision of biotech professionals. This study employs a qualitative methodological approach, comprising an extensive literature review coupled with a case study analysis, to reflect on the participation of metaverse technologies within the biotechnology sector. This systematic review focuses on the transformative role of the metaverse in biotechnolo-gy, analysing its capacity to enable global collaboration, advanced simulations, and immer-sive education. By synthesising peer-reviewed literature (2019-2025), we highlight key ad-vancements, such as AI-driven drug discovery and virtual laboratories, while addressing critical challenges, including data privacy, ethical concerns, and computational require-ments. In this review, we aim to highlight the metaverse's potential to transform biotechno-logical research and emphasise the need for interdisciplinary solutions to harness its bene-fits. Drawing on an analysis of trends in cloud collaboration, digital simulation, immersive learning, and ethical issues, the research provides a critical analysis of the challenges and problems posed by the digital revolution. Key areas discussed in immense detail include data privacy, algorithm bias, computational infrastructure, and regulatory uncertainty. Our findings emphasise the need for interdisciplinary research and the provision of comprehensive ethi-cal and technical guidelines to enable the secure and equitable use of metaverse technologies in biotech-nology. This study will primarily contribute to the growing corpus of scholarly literature by providing a concise and logical synthesis of existing knowledge, identifying key areas for future research and devel-opment.

Keywords: Metaverse, Biotechnological Innovation, Virtual Collaboration, Immersive Environments, Digital Twins, Simulation, Data Security

1. Introduction

The metaverse is a virtual networking space that incorporates various technologies, like Virtual Reality (VR), Augmented Reality (AR), Blockchain, and Artificial Intelligence (AI). It presents a transformative potential for biotechnological developments (Mystakidis, 2022; Lee, 2021). The review synthesises the current research to explore how metaverse technologies drive innovation in biotechnology, from virtual labs to AI-powered clinical trials. The capabilities of this emerging digital ecosystem enable a new era of virtual interaction, overcoming traditional research obstacles. The metaverse adopts an environment that enables academic researchers, scientists, and industrial professionals to optimise their time, facilitating efficient collaborative work and advanced research, achieving the desired speed and effectiveness.

With continuous advancement in the network infrastructure and computational power, the evolution of the metaverse is growing rapidly and becoming a robust platform that supports real-time developments, immersive experiences across medicine, scientific research, and educational training (Shen, 2025; Uddin, 2024).

Biotechnology is an advanced discipline that encompasses complex biological processes, such as genetic modification, computational analysis, and drug discovery. They require high-level interdisciplinary collaborative work, the use of advanced simulation techniques, and big data analysis to support high-probability decision-making (Bordukova, 2023; Mercado, 2023).

In conventional settings, research is often hindered by natural restraints, partly due to limited access to the laboratory's equipment and the high costs of the experiments. In contrast, in the metaverse, the transformative solution through virtual labs enables scientists to engage in virtual experimentation (Mercado, 2023).

The latest research suggests that the integration of virtual reality into biotechnological advancements has paved the way for discoveries. Innovation includes AI-based drug discovery, virtual clinical trials, and cross-border global collaboration. By studying virtual clinical trials, we create patient representations, called *digital twins*. Virtual constructs that enable the testing of molecular drugs in their preliminary stages prior to traditional clinical trials are made possible through digital twins (Venkatesh, 2022).

Digital twins are utilised for various purposes, such as testing, simulation, and adapting models from the physical to the virtual world, allowing failures to be predicted. In contrast to traditional clinical trials, digital twins facilitate the initial stages of virtual constructs testing for molecular drugs in medicine. Simulation, based on Artificial Intelligence, enables research on real-time virtual models. Additionally, the metaverse gives the possibility for researchers to connect without any geographical constraints (Venkatesh, 2022).

The potential of the metaverse in biotechnology also raises several challenges. Securing data in the metaverse remains the main critical issue. Data (such as genetic and medical information) about patients must be protected from misuse, vulnerabilities and cyber threats. Another challenge of the metaverse includes the demand for computational resources, such as cloud storage, powerful Graphical Processing Units (GPUs), and high-speed internet connections, which may not be available to all researchers worldwide (Mosharraf, 2025).

Policies surrounding ethics will be significantly important for scientific accuracy when dealing with virtual constructions and simulations. The privacy of participants, informed consent in virtual trials, and the right to equitable access to resources within the metaverse require attention to avoid discrimination and inequality gaps in biotechnological advancements (Mosharraf, 2025; Kaddoura, 2023).

The integration of the metaverse into biotechnology is a specific problem, which, however, has already captured the interest of numerous businesses and academic research institutions willing to invest in focused research and development. In practice, the merging of different technologies is not limited to research and development; it also revolutionises teaching and training in the industrial biotechnological sector.

Students and professionals can externally visualise complicated biological concepts in a 3-dimensional (3D) environment using the metaverse, which makes it easier for them to grasp and apply the information provided. The acquisition of practical skills, combined with enhanced retention of knowledge, proves beneficial. Advanced virtual laboratories have the potential to be invaluable in the education of future biotechnologists and medical professionals (Kaddoura, 2023; Venkatesh, 2022; Petrigna, 2022).

This review paper is structured as follows. Section 2 reviews the relevant work-related publications, focused on the most important milestones in understanding metaverse use in biotechnology. In Section 3, we discuss the methodology of how the virtual metaverse simulation influences our understanding of major concepts in a biological system. Section 4 discusses the main findings. In Section 5, we discuss the most significant practices of integrating the metaverse in biotechnology.

Finally, we draw the main conclusions of this study in Section 6.

2. Literature Review

The integration of metaverse technologies into biotechnology has taken significant attention in recent years, with exploration of their potential use in promoting collaborative work, accelerating drug discovery, and revolutionising medical training (Mystakidis, 2022; OOi et al., 2024). This literature review categorises the existing body of knowledge into four key areas: (i) the convergence of metaverse technologies with biotechnology, (ii) the role of AI, digital twins, and simulation in a biotech research, (iii) immersive training and education platforms within the metaverse, and (iv) data privacy, security and integrity, and ethical issues related with virtual environments of biotechnological resources.

2.1 Metaverse and Biotechnological Convergence

The metaverse serves as an interconnected virtual space that enables individuals to interact with each other utilising digital avatars. This is an ongoing, rapidly evolving experience. Additionally, other fields have found it helpful, including healthcare and biotechnology (Mystakidis, 2022). Bioinformatics research is undergoing a transformation with the integration of virtual environments (Taylor, 2022). It has been found that interactive 3D models significantly aid in the understanding of large and complex biological systems. By utilising these models in the field of bioinformatics, researchers can gain a deeper understanding of the types of structures and processes that take place at the molecular level.

Biotechnology researchers are increasingly employing metaverse technologies to mimic complex biological systems. Molecular dynamics simulations in virtual reality enable an interactive and intuitive experience with proteins and their interactions in cells (Deeks, 2020). This highly interactive approach may allow us in the future to literally look inside a simulated organism at a molecular level—an engineering achievement that could someday transform medicine. Drug delivery systems (DDS) that release their payload in the appropriate quantity at the proper time and location will propel the discipline toward more efficient, targeted, and personalised therapy. Increasing insight in these areas, owing to VR, can only serve to advance biomedicine.

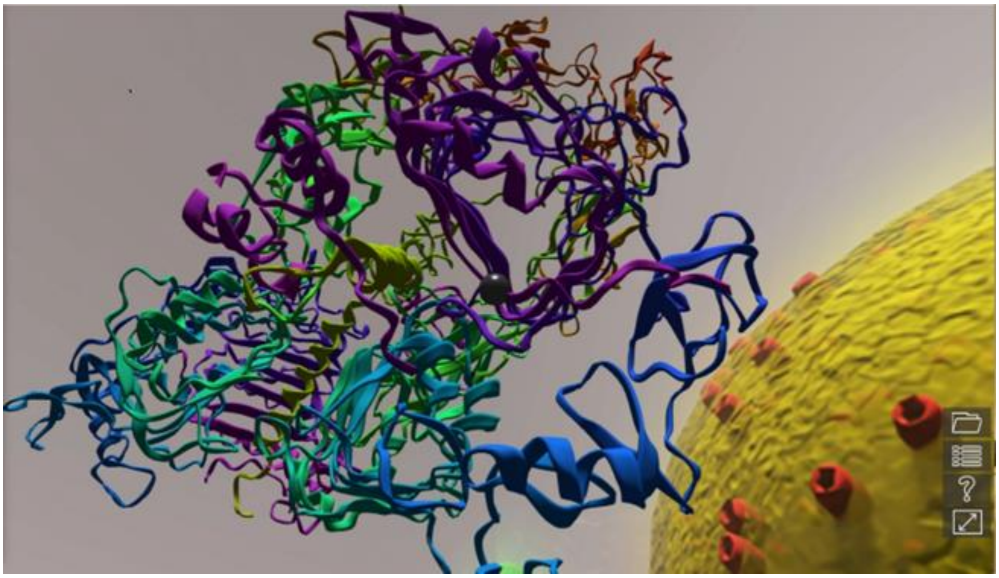


Figure 1 illustrates, as an example, the virtual reality of an insulin protein (T. Gutmann, 2019), as prepared using the ProteinVR software (Cassidy KC, 2020).

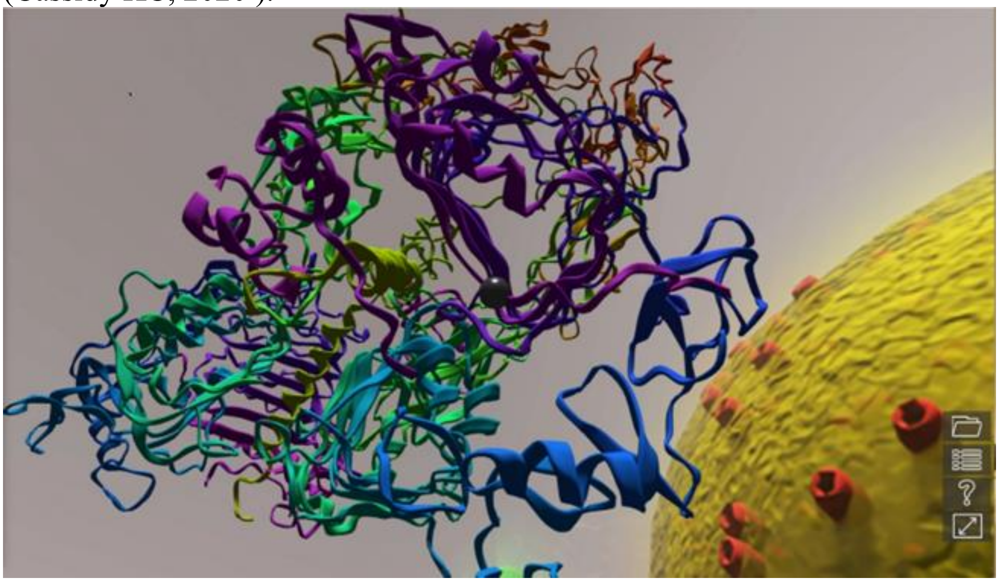


Figure 1: Human insulin receptor ectodomain bound by four insulins in an intercellular virtual environment created by the ProteinVR software (Cassidy KC, 2020)

Furthermore, remote collaboration platforms powered by the metaverse are breaking down geographical boundaries, allowing international research consortia to conduct joint experiments in virtual labs. According to Lee et al., these platforms are found to be especially useful during the COVID-19 pandemic era, when travel was heavily restricted and organisations had to turn to substitutes for maintaining the kind of collaborative biomedical research that typically takes place at numerous locations (Williams, 2023).

Ultimately, the use of virtual environments in bioinformatics enhances research and enables unprecedented global collaboration, leading to entirely new, groundbreaking solutions that are quite possible in this space. Despite these advantages, some challenges arise regarding the standardisation of metaverse applications in biotechnology. Notably, the lack of universal regulatory frameworks and the high cost of metaverse hardware have limited its widespread adoption (Chengoden, 2023).

2.2 AI, Digital Twins, and Simulation in Biotechnology

Artificial intelligence and digital twin technologies are at the heart of the metaverse-based biotechnology revolution. AI algorithms improve predictive modelling in drug discovery, and digital twins (virtual replicas of the same biological systems) allow for personalised simulation of disease progression and response to their treatment (Patel, 2022; Wang, 2023)

Digital twins have also proven to be of great significance in clinical trial planning, enabling scientists to run virtual trials on AI-modelled patient simulations prior to proceeding to human trials. Patel indicates that digital twins can reduce the duration and expenses of traditional clinical trials by approximately 40%, and thereby enhance the effectiveness of experimental treatments (Patel, 2022). Similarly, Wang et al. highlight the role of AI in streamlining medical drug development, employing metaverse-based digital twins as a mean to optimise molecule production processes (Wang, 2023).

Virtual reality-based surgery simulations, coupled with an AI-powered feedback system, have also significantly improved the precision in the field of medicine (Gani, 2022). Such immersive technologies enable biomedical engineering researchers and clinicians to refine and implement their technical skills in an adaptable and risk-free setting. Simulation of obscure stages with real-time feedback, these systems, known as in-silico, enhance surgical precision, reduce errors, and streamline overall medical training before it occurs either in vitro or in vivo.

2.3 Immersive Training and Education in Biotechnology

The metaverse has introduced new methods of learning and professional development in biotechnology. Traditional models of learning are textbook-based and utilise static 2-dimensional (2D) diagrams, which are insufficient to explain the complexity of some systems, such as the cells and biological molecular structures. Interactive VR-based learning systems, on the other hand, provide interactive 3D learning modules that significantly enhance knowledge retention (Mystakidis, 2022).

For example, Tsai et al. contrasted conventional medical instruction with metaverse instruction. The study revealed that students subjected to VR learning systems demonstrated a 25% improvement in comprehension and a 30% increase in procedural accuracy for laboratory simulations (Tsai, 2022). Wiederhold reported similar findings, revealing that medical professionals trained in VR environments were more competent and self-assured when performing real surgeries (Wiederhold, 2022).

Another application of the metaverse in education is the establishment of virtual laboratories, which allow researchers and students to conduct experiments in controlled, secure virtual environments (Taylor, 2022). The laboratories provide access to high-end equipment that may be prohibitively expensive due to budget constraints, facilitating inclusive high-level biotechnological research.

However, viability for metaverse learning depends on accessibility and infrastructure. Prohibitive expenses on VR hardware and software development may eliminate large-scale use in low-income regions (Kim, Lee, & Choi, 2023). In addition, inclusivity in virtual learning environments encompasses consideration of factors, such as the compatibility of haptic devices for individuals with disabilities (Kostick-Quenet, 2023).

3. Methodology

This is a qualitative research study aimed to examine the effect of metaverse applications on biotechnological innovation with a focus on artificial intelligence, digital twins, virtual reality, and augmented reality applications. A methodological framework is designed to provide an integrative synthesis of existing research, utilising a systematic literature review followed by chosen case studies. These enable a comprehensive understanding of metaverse technologies in the biotechnology sector.

3.1 Research Design

The study is exploratory and attempts to investigate and explain the prevailing knowledge on biotechnology applications in the metaverse. Here, the systematic literature review aimed to define key technological leaps, strengths, and weaknesses of the emerging technology. A comparative evaluation of metaverse-driven educational training models and digital twins infused with AI in clinical research was conducted to validate findings.

3.2 Data Collection

Data for this study were collected from peer-reviewed journal articles, conference proceedings, government reports, and industry white papers published between 2019 and 2025. Principal databases used were:

- PubMed (for biomedical and clinical applications) (PubMed, 2025)
- IEEE Xplore (for AI and digital twin technologies) (IEEE Xplore Digital Library, 2025)
- SpringerLink & ScienceDirect (for interdisciplinary biotechnology applications) (SpringerLink, 2025) (ScienceDirect, 2025)
- Google Scholar (for supplementary academic literature) (Google Scholar, 2025)

The search criteria included terms, such as (PubMed, 2025; SpringerLink, 2025):

- "Metaverse in biotechnology,"
- "AI-driven molecule drug discovery in medicine,"
- "Digital twins in healthcare,"
- "VR-based medical training,"
- "Metaverse and sustainability in biotech."

The so-called "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) model (Nikulina, Simon, Ny, & Baumann, 2019) and its guidelines were utilised in this study to select the information, which is known for its accuracy and suitability.

3.3 Data Analysis

The collected literature was examined utilising thematic content analysis to identify emerging trends and recurring themes. Our analysis focused on four primary themes derived from the literature review, as outlined in the following.

1. The Convergence of the Metaverse and Biotechnology: The focus was on examining the impact of VR, AR, and AI-powered digital twins in pharmaceutical development and biological research.
2. AI and Digital Twin Technologies in Clinical Applications: Here, we aim to evaluate their role in molecular medicine drug development, precision in medicine, and virtual clinical trials.
3. Immersive Education and Training in Biotechnology: We evaluated the effectiveness of VR-based learning models compared to conventional methods.
4. Ethical, Regulatory, and Sustainability Challenges: We aimed to analyse the ethical concerns regarding bias in AI, data privacy and

security, and the environmental impact of applications demanding high computational power.

3.4 Case Study Approach

We conducted a case study analysis to examine the implementation of virtual clinical trials as a complement to the literature review. For that, we utilised digital twin models. The case study employed real-world applications of AI-powered simulations in molecular drug testing in medicine and patient modelling, thereby evaluating their efficiency, accuracy, and limitations.

3.5 Reliability and Validity

- Reliability: Our study included only peer-reviewed studies and high-impact sources to ensure consistency and validity. Gathered studies were cross-verified across multiple databases.
- Validity: We compared the findings with real-world case studies and expert opinions from white papers published by the World Health Organisation (WHO), MIT Technology Review, and Harvard Medical School.

3.6 Limitations

- Technological Scope: The study is limited to AI, VR, AR, and digital twin applications in biotechnology. Other emerging technologies (e.g., quantum computing and blockchain in biotech) were not extensively covered.
- Timeframe: Due to rapid technological advancements, some findings may become outdated as newer research emerges.
- Data Availability: Some proprietary industry reports were inaccessible, restricting insights into specific commercial applications of the metaverse in biotechnology.

4. Findings

From the analysis of published research and case studies, we found various crucial findings concerning the impact of metaverse technologies (including AI, digital twins, VR, and AR) on biotechnological innovation. The outcomes indicate how these technologies are transforming research practice, clinical trials, medical education, and sustainability activities in the field of biotechnology.

The findings are organised into five major areas, which are described in the following discussion.

1. Metaverse-Enabled Virtual Collaboration in Biotechnology.

2. AI-Driven Simulation and Digital Twins in Drug Discovery and Clinical Trials.
3. Immersive Learning and Training through VR-Based Education.
4. Metaverse challenges in Data Security, Ethical AI, and Privacy.

4.1 Metaverse-Enabled Virtual Collaboration in Biotechnology

The most significant impact of the metaverse includes its ability to facilitate global collaboration between biotechnology researchers, pharmaceutical companies, and healthcare institutions. Virtual laboratories and digital research environments eliminate geographical constraints, enabling real-time experimentation, data sharing, and AI-driven modelling.

Case Study: Virtual Research Laboratories

A study by Lee et al. (2022) found that metaverse-based research environments increased collaboration efficiency by 35% compared to traditional lab-based work. Researchers in different locations could simulate protein-folding experiments in shared virtual spaces, analyse molecular interactions in 3D, and conduct remote-controlled lab experiments without requiring physical access to laboratory infrastructure (Lee, 2021).

Key Findings:

- Virtual collaboration allows interdisciplinary teams to access high-resolution simulations, real-time data, and AI-assisted molecular modelling.
- Global teams can replicate laboratory conditions in the metaverse without expensive physical resources.
- Real-time VR-based interactions in virtual biotechnological hubs provide faster peer reviewing and knowledge transfer.

4.2 AI-Driven Simulation and Digital Twins in Drug Discovery and Clinical Trials

AI-powered digital twins, precise virtual replicas of human patients, cells, and molecular-level interactions of medical drugs, are revolutionising drug development in medicine and clinical trials. These data-driven models simulate disease progression, predict patient-specific treatment responses, and reduce reliance on traditional animal and human testing.

Findings from AI-Powered Drug Discovery Models

- Patel (2022) reports that AI-driven drug simulations reduce the average drug development timeline from 12 years to 5 years by predicting molecular interactions more efficiently than traditional testing (Patel, 2022).

- Wang et al. (2023) highlight that digital twins improve personalised medicine accuracy by 40%, allowing for targeted drug design based on real-time biological data (Wang, 2023).
- AI-powered models can test millions of drug compounds in silico, identifying the most promising candidates in weeks instead of years.

Case Study: AI-Powered Simulations and Digital Twin Models in Drug Testing

Ren et al. (2025) demonstrated a groundbreaking application of AI-driven digital twin technology in Alzheimer's disease (AD) research, as seen in their work on virtual clinical trials and precision drug discovery. The study leveraged multi-omics data (genomics, transcriptomics, and proteomics) and longitudinal clinical records from leading Alzheimer's disease databases (e.g., ADNI, ROS-MAP, and electronic health record systems) to construct patient-specific digital twins. These AI-powered virtual models simulated disease progression under various drug interventions, enabling in silico clinical trials that reduced reliance on large control groups and accelerated therapeutic validation (Yunxiao Ren, 2025).

A key innovation was the integration of network-based AI frameworks (e.g., GPSnet) with data-driven generated perturbation responses. By combining GWAS data and single-cell RNA sequencing, researchers identified medical drugs, such as anti-inflammatory agents, with potential efficacy against Alzheimer's disease (Yunxiao Ren, 2025). Additionally, DTs were continuously updated with real-time biomarker data (such as MRI/PET imaging, CSF, and blood biomarkers), which provided higher predictions of early disease detection and significantly improved personalised treatment procedures.

While maintaining high predictive accuracy, this approach reduces the development timelines and costs compared with traditional clinical trials. The success of these AI-powered simulations highlights the transformative potential of digital twin technology in precision medicine, providing a faster and more efficient pathway to drug discovery for complex neurodegenerative diseases (Yunxiao Ren, 2025).

4.3 Immersive Learning and Training through VR-Based Education

Virtual reality and augmented reality enhance medical and biotechnological education by providing immersive, interactive learning environments. Students and professionals can engage in 3D molecular modelling, real-time anatomical dissection, and virtual surgery training within the metaverse.

Findings from VR-Based Medical Training

- Tsai et al. (2022) conducted a comparative study on VR-based medical education vs. traditional classroom learning. Results showed that:
    - Students in VR environments demonstrated a 25% increase in comprehension.
    - Procedural accuracy improved by 30% when learning via interactive 3D models.
    - Knowledge retention rates were 20% higher in VR-based medical training compared to textbook-based learning (Tsai, 2022).

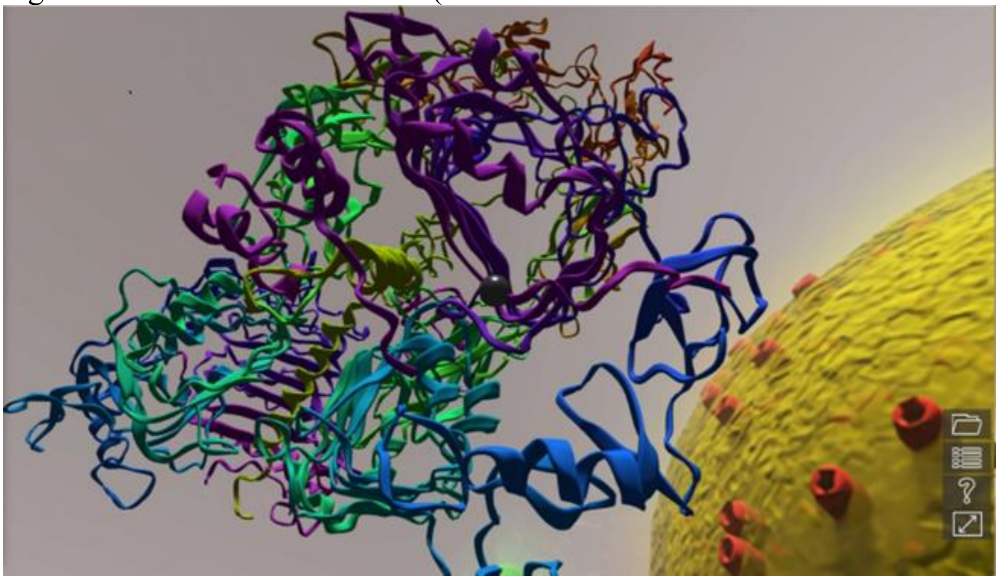
Case Study: VR in Surgical Training

A study by Wiederhold (2022) discovered that professionals trained in the use of virtual reality environments were approximately 29% more accurate in real-world surgeries compared with those using only traditional cadaver-based methods. Furthermore, now the University of California Medical Centre integrates VR surgical simulations for real-time haptic feedback training (Wiederhold, 2022).

Key Findings:

- VR-based medical training improves precision, comprehension, and retention rates among students and professionals.
- Real-time haptic feedback simulations allow surgeons to practice complex stages. Then, they apply them to real patients.
- Biotechnology education process benefits from interactive modelling at a molecular level, allowing students, for example, to manipulate DNA and protein structures in a fully immersive

digital environment (as demonstrated in



- Figure 1).

4.4 Challenges in Data Security, Ethical AI, and Privacy in the Metaverse

With the adoption of metaverse technologies in biotechnology, security, privacy, and ethical concerns remain significant challenges. AI-driven decision-making models, digital twins, and VR-based patient data management raise concerns over data protection, patient confidentiality, and algorithmic biases.

Findings on AI Bias and Ethical Challenges

- Shah et al. (2024) highlighted concerns that 80% of AI-powered clinical trial datasets still rely on Western-centric medical data, potentially misrepresenting global patient populations (Shah, 2024).
- Rahimzadeh found that AI models in digital twin healthcare applications showed biases in diagnostic accuracy, with up to 15% higher error rates for underrepresented demographic groups (Rahimzadeh).

Discussion

The combination of AI, digital twins, AR, and VR in biotechnology is revolutionising drug discovery, medical education, and clinical trials through greater efficiency, cost-effectiveness, and global collaboration. AI-powered digital twins enhance drug development by reducing reliance on physical testing and improving accuracy in precision medicine, while virtual clinical trials reduce cost and risk for pharmaceutical companies (Patel, 2022). Second, VR-based training in medicine enhances procedural accuracy and knowledge retention, enabling students and medical professionals to hone complex techniques in simulated environments (Tsai, 2022). However, AI bias, regulatory gaps, and data security attacks remain pressing concerns, as AI-assisted healthcare models must be rigorously tested to prevent diagnosis errors and ensure effective treatment protocols (Kostick-Quenet, 2023).

Moreover, metaverse apps require enormous amounts of computational capabilities, which have implications for sustainability, with AI model energy consumption having no signs of decline (Shah, 2024). Improved AI regulation, ethical standards, and environmentally friendly computing solutions are required to realise the full potential of the metaverse in biotechnology.

In the classroom environment, the teaching methodology should incorporate a variety of supportive learning techniques, including scientific reading materials, data structures, tables and graphs, videos, interactive discussion, animations, and software. They should be combined with problem and project-based learning methodologies, including AR, VR, and AI technologies (Goldstein, 2016) (W. Muliawan, 2016) (S. T. Kanyesigye, 2022) (J. R. C., 2024) (J. A. V., 2024) (J. P. W., 2024) (Vaughan, 2016). More importantly, the students should be prepared to identify the most important quantities and to measure and identify trends in the user data, utilising data processing tools and graphics (Vaughan, 2016).

Conclusion

The integration of the metaverse into biotechnology is a paradigm shift in research, medical education, drug discovery, and clinical practice. Artificial intelligence, digital twins, virtual reality, and augmented reality are fuelling innovation, driving precision, and making collaboration possible in ways previously impossible. AI-accelerated drug discovery and digital twins are reducing the time to conduct clinical trials and decreasing their expenses, while VR-facilitated medical education enhances comprehension, procedural accuracy, and real-world preparedness among medical professionals (Patel, 2022; Tsai, 2022). The findings of this study suggest the metaverse's potential for revolutionising biotechnology; however, the most important technological, ethical, and regulatory challenges must be addressed correctly.

Even with such advancements, some of the main concerns remain, including AI bias, data privacy threats, regulatory ambiguity, and excessive computational requirements. AI-based medical applications must be thoroughly tested to prevent misdiagnosis, biased treatment recommendations, or uncertain digital twin simulation (Kostick-Quenet, 2023).

Furthermore, a concern of paramount importance is data security because metaverse platforms handle vast amounts of sensitive patient and research data that must be protected from cybersecurity attacks and unauthorised access.

Moreover, the sustainability of metaverse applications is also a growing concern, as AI-based biotech studies and VR-based simulation necessitate enormous processing strength, thereby increasing energy consumption and footprint (Shah, 2024). For the potential of the metaverse in biotechnology to be fully exploited, interdisciplinary collaboration among technologists, scientists, healthcare practitioners, and policymakers must be enabled. Regulatory frameworks for AI need to be reorganised to enable AI-based clinical trials, and the ethical norms must be established to minimise bias.

The so-called green computing solutions must be accorded high priority to render metaverse applications eco-friendly. Continued investment in research, AI ethics, and cybersecurity will be crucial in ensuring the safe, ethical, and efficient deployment of metaverse-driven biotechnological innovations.

Lastly, the future of biotechnology within the metaverse is auspicious; however, it will ride on responsible innovation, rigorous verification, and effective governance. The biotechnological industry can utilise metaverse technology to improve healthcare globally, clinical training, research efficiency, and further address such concerns. That ensures a more united, accessible, and technologically enhanced world.

The use of these advanced technologies focuses on fostering self-directed curiosity about real-world issues and, simultaneously, encouraging social interaction during the learning process (V. K. LaBoskey, 2004; Vygotsky, 1978).

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Data Availability: All data are included in the content of the paper.

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