**Transforming Education in Nigeria through Science, Technology and Innovation: Opportunities and Challenges**

**Abstract**

*The integration of science, technology, and innovation into education has influenced educational practices and policies, but its adoption remains limited in Nigeria, hindering the country's educational progress. This study aimed to examine the impact of science, technology, and innovation on educational transformation in Nigeria, focusing on utilising emerging technologies to improve learning outcomes. The study employed a qualitative approach based on a systematic review and analysis of existing literature to gain comprehensive insights into the role of science, technology, and innovation in educational transformation. This investigation was grounded in the theoretical frameworks of constructivism and connectivism, which provided a foundation for understanding the complex interactions between technology, learning, and educational innovation. Data were collected through case studies and analysed using thematic analysis. The findings showed that emerging technologies such as AI, blockchain, and VR can personalise learning, improve accessibility, and promote inclusivity in Nigerian education. However, challenges like infrastructure shortages, limited teacher training, and policy gaps impede the effective integration of science, technology, and innovation in education. The study's findings have implications not only for Nigeria but also for other developing countries facing similar challenges in leveraging technology for educational development, highlighting the need for context-specific solutions and collaborative efforts to bridge the digital divide. The study concludes that policymakers, educators, and stakeholders must work together to address these issues and harness the potential of science, technology, and innovation to transform Nigerian education. Based on the findings, the study recommends investing in infrastructure, providing continuous teacher training, and developing policies that support innovation and technology integration in education.*

**Keywords:** Science, Technology, Innovation, Educational Transformation, Emerging Technologies.

**Introduction**

The rapid advancement of science, technology, and innovation has altered the educational scene, presenting both opportunities for growth and challenges that can impact Nigeria's progress. As global interconnectivity increases, the need for educational systems to adapt and innovate has never been greater (Hapgood et al., 2020). This research investigates the role of science, technology, and innovation in facilitating educational transformation.

Science, technology, and innovation (STI) have fundamentally altered education. This is evident in how it has changed the way pupils learn and professors teach in a typical Nigerian classroom. Science influences education by providing a framework for inquiry-based learning, critical and creative thinking, and problem solving (National Research Council, 2012). Science

education has also helped children have a better grasp of the natural world, cultivating curiosity and encouraging research (Bybee, 2010). By introducing science into education, students can learn and use fundamental science process skills such as observation, experimentation, and analysis, which are critical for success in a variety of professions both within and outside of school (Osborne & Dillon, 2008). Harnessing science, technology, and innovation (STI) in education has the potential to revolutionise the way we learn and teach. As such, leveraging digital technologies, educators can create more equitable and inclusive learning environments that support students from diverse backgrounds and prior preparations. According to Chiu et al. (2024), digital technologies can be used to present and visualise scientific theories and concepts effectively, while pedagogic innovations require collective, interdisciplinary research efforts.

***Figure 1: Interlink of Science, Technology, Innovation and Education***

The relationship between science and technology has the potential to profoundly impact education, which can transform the way students learn and teachers teach. This might be because many scientific discoveries in various fields have led to the development of new technologies, which in turn have transformed the education sector as follows:

1. Several advances in Physics and Computer Science have enabled the creation of computing devices, which have become essential tools in modern education (Bates, 2015).
2. The development of the internet, a direct result of scientific research in computer networking, has further expanded access to educational resources and opportunities.
3. Another notable example of scientific discovery driving technological innovation in education is the development of Artificial Intelligence (AI). AI-powered adaptive learning systems can personalise instruction, providing real-time feedback and adjusting the difficulty level of teaching materials based on individual students' performance (Shute & Zapata-Rivera, 2012).
4. The development of virtual reality (VR) and augmented reality (AR) technologies, which have been made possible by advances in computer science and engineering. These technologies can create immersive and interactive learning experiences, making complex concepts more accessible and engaging (Dunleavy & Dede, 2014). AR is a technology that focuses on augmenting the physical world or phenomenon with digital artefacts, images, videos, or experiences overlayed with computer-generated images (CGI) and 3D models. VR aims to create a virtual experience with headsets and tracking to place the user in a different world.

This technology has the potential to greatly improve student results by allowing for more personalised training and support. These technological advances have had a profound impact on schooling. Foremost among these are:

1. Online learning platforms and digital libraries provide global access to educational resources, including instructional materials, research publications, and multimedia content (Means et al., 2010).
2. Learning Management Systems (LMS) provide online learning by providing students with access to course materials, assignments, and grades.

It is vital to note that by using these technologies, educators may develop more effective, engaging, and student-centered learning experiences that will prepare students for success in a rapidly changing world. The link between science and technology has had a significant impact on the education sector, allowing for the creation of new technologies that improve student learning outcomes and broaden educational resource access. This implies that as scientific research drives technological innovation, education will most certainly continue to advance, adopting new technology and methodologies that improve the learning experience.

Another key notion in this area is educational innovation, which refers to the development and application of new ideas, approaches, and technology to improve teaching and learning. This entails implementing novel teaching and learning strategies, such as gamification, simulation-based learning, and flipped classrooms, which have been shown to improve student engagement, motivation, and academic performance (Hamari et al., 2014; Vlachopoulos and Makri, 2017; Sookoo and Boisselle, 2018). Furthermore, education innovation includes the use of data analytics and artificial intelligence to customise learning, forecast student outcomes, and identify areas for improvement (Shute & Zapata-Rivera, 2012). Emerging technologies like artificial intelligence (AI), blockchain, and virtual reality (VR) are revolutionising education. AI-powered adaptive learning systems can tailor training to improve student engagement and outcomes (Zawacki-Richter et al., 2019). Blockchain technology can make credentialing more secure and transparent, whilst virtual reality can enable immersive learning experiences that mimic real-world surroundings (Freina & Ott, 2015). STEM education, which combines science, technology, engineering, and mathematics, is essential for educating students for the challenges of the twenty-first century (Bybee, 2013). The incorporation of emerging technologies such as AI, blockchain, and VR into STEM education has the potential to significantly and favourably improve learning experiences, student outcomes, and prepare the next generation for success in an increasingly complicated and technologically driven society.

**Conceptual Review**

**Science as the Foundation of Knowledge**

Science is a systematic and structured approach to exploring the natural world that involves observation, experimentation, and evidence-based reasoning (National Research Council, 2012). It includes a variety of disciplines, including physics, biology, and chemistry, all of which strive to comprehend the fundamental laws and mechanisms that govern our universe (Osborne & Dillon, 2008). Science promotes critical thinking, curiosity, and problem-solving abilities, making it an important component of education (Bybee, 2010). By investigating scientific concepts and processes, students have a greater grasp of their surroundings and are better prepared to face challenging issues.

Furthermore, science education can be divided into three domains: content knowledge, scientific inquiry, and scientific practices (National Research Council, 2012). Content knowledge refers to the facts and concepts that students acquire in science, whereas scientific inquiry refers to the procedures and abilities required to undertake scientific investigations. Observing (noticing and recording phenomena), Questioning (asking questions about observations), Hypothesizing (formulating educated guesses), Predicting (forecasting outcomes), Experimenting (designing and carrying out experiments), Measuring (collecting quantitative data), Analyzing (interpreting data), Concluding (drawing conclusions based on evidence), and Communicating (effectively sharing results).

Scientific practices, on the other hand, refer to the methods by which scientists and engineers approach problems and devise solutions. One possible mistake regarding these principles is that science is all about memorisation and rote learning, rather than critical thinking and problem solving (Osborne and Dillon, 2008). As such, science can be defined as a systematic and structured approach to investigating the natural world through observation, investigation, and evidence-based reasoning, to understand the fundamental laws and mechanisms that control our universe.

The image below depicts how the study of science, which includes Physics, Chemistry, and Biology, plays an important part in developing students' key abilities and attributes such as curiosity, problem-solving, creative thinking, and critical thinking. Students get a better grasp of the natural world, learn how to tackle complicated problems systematically, and build critical thinking and logical reasoning skills by investigating scientific concepts and principles. This, in turn, alters education by promoting curiosity, creativity, and innovation, preparing students for employment in STEM industries and beyond, and equipping them with the skills necessary to address the challenges of the twenty-first century.

Fig. 2: Science and Students' 21st Century Skills Development

**Technology as the Enabler of Progress in Teaching and Learning**

Technology is the application of scientific knowledge to practical goals, such as the creation of tools, machines, and systems that improve human life and productivity (Kozma, 2003). Technology transforms education by enabling students to access vast amounts of information, facilitating collaboration, and providing personalised learning experiences (Bates, 2015). Digital tools, such as learning management systems and online materials, have swiftly altered the way students learn and teachers teach, making education more accessible, adaptable, and efficient.

Furthermore, technology can be utilized to assist a variety of learning goals, including knowledge acquisition, skill development, and attitude formation (Dabbagh & Kitsantas, 2012). Multimedia resources, such as movies and simulations, can help students engage and understand complicated subjects. Online platforms and learning management systems can also help students and teachers communicate and collaborate, fostering a sense of belonging and social learning. A common fallacy in the literature is that technology is a cure-all for education, rather than a tool that must be used intelligently and effectively (Bates, 2015). Based on the above, technology can be defined as the application of scientific knowledge to practical goals, such as the creation of tools, machines, and systems that improve human life, productivity, and learning opportunities.

Figure 2 depicts technology as a powerful enabler of educational progress, transforming the learning experience by providing access to vast resources, facilitating personalized instruction, and encouraging collaboration and creativity, all of which improve student engagement, outcomes, and preparation for success in an increasingly digital world.

*Figure 3: Technology and Improvement in Education*

**Innovation as the Driver of Progress in Education**

Innovation is the development and execution of new ideas, products, and procedures to propel progress and improvement (Hannan & Silver, 2000). In education, innovation can take numerous forms, such as developing new teaching methods, utilizing emerging technologies, and creating unique learning environments (Hamari et al., 2014). Educational innovation attempts to improve student results, increase efficiency, and promote equity and access (Shute & Zapata-Rivera, 2012).

Furthermore, innovative education necessitates a culture of experimentation, risk-taking, and ongoing development (Hannan & Silver, 2000). Educators and politicians must be open to question established practices and consider new options, employing technology and other resources to encourage innovation and development. By cultivating an innovative culture, educators may develop more effective, engaging, and student-centered learning experiences that prepare students for success in a rapidly changing environment. Some may regard innovation as a term or trend, rather than a key driver of progress and improvement (Hannan and Silver, 2000). In effect, innovation may be defined as the development and execution of new ideas, products, and procedures that promote advancement, improvement, and positive change, frequently utilizing technology and other resources to achieve desired results.

Figure 4 depicts how innovation is a key driver of progress in education, transforming the learning experience by introducing new teaching methods, leveraging cutting-edge technologies, and encouraging creativity and critical thinking, thereby improving student engagement, outcomes, and preparation for success in an increasingly complex and dynamic world.

*Figure 4: Innovation and Education Advancement*

**Education as the Key to Unlocking Students’ Potential**

Education is the process of obtaining knowledge, skills, and values that allow people to realize their full potential and contribute to society (Garrison & Kanuka, 2004). It includes a variety of components, including as formal education, informal learning, and lifelong learning, all of which play an important part in personal and professional growth. Education should be tailored to the requirements of various students, encourage critical thinking and problem-solving skills, and develop creativity and innovation (Means et al., 2010).

Furthermore, education is divided into three levels: primary, secondary, and postsecondary, each with its own set of characteristics and goals (OECD, 2019). Primary education focuses on fundamental skills and information, whereas secondary education expands on these foundations and prepares students for higher education or employment. Tertiary education, on the other hand, offers advanced training and specialization in specific areas, preparing students for professional vocations or future study. Education may be viewed as a one-size-fits-all concept, rather than a complicated and nuanced process necessitating customized methods and solutions. Education can thus be defined as a multifaceted process of acquiring knowledge, skills, and values that enable individuals to reach their full potential, contribute to society, and pursue lifelong learning. It includes formal education, informal learning, and personal development.

Finally, science, technology, innovation, and education are interwoven concepts that shape our view of the world while promoting development and betterment. While these concepts are frequently discussed independently, they are inextricably linked, and a thorough understanding of each is required for making sound decisions and implementing effective policies.

**Theoretical Framework**

1. **Science, Technology, and Innovation in Empowering Constructivist Learning**

This study is based on constructivist theory, which states that learners construct knowledge through active involvement with their surroundings (Piaget, 1954). The incorporation of science, technology, and innovation into education can help students develop critical thinking, problem-solving, and teamwork abilities (Jonassen, 2000). Constructivism is a learning theory that holds that individuals create knowledge and meaning via their experiences and interactions with their surroundings (Piaget, 1954). This idea stresses learners' active engagement in developing knowledge rather than passively accepting information. Key themes include active learning, student-centred techniques, contextual learning, and social engagement.

Constructivism can be used in education in the form of project-based learning, inquiry-based learning, and STEM education to help students develop critical thinking and problem-solving skills. Recent research has effectively integrated constructivist ideas into STEM education, online learning, and game-based learning, resulting in increased engagement and better learning results (Honey et al., 2014; Garrison et al., 2000; Shute, 2008).

The incorporation of science, technology, and innovation into education can promote constructivist learning, allowing students to investigate real-world problems and propose solutions. Using these approaches, educators may design learning environments that promote critical thinking, cooperation, and creativity, preparing students for success in a rapidly changing world.

Constructivism's emphasis on active learning and social interaction is consistent with modern educational aims, which prioritize the development of abilities such as critical thinking, problem solving, and teamwork. Educators who understand constructivist concepts can create more effective learning experiences that meet the requirements of a varied range of students.

Science, technology, and innovation enable learners to build knowledge through hands-on experimentation and problem solving, which is consistent with constructivism's emphasis on experiential learning. Using these elements, educators may design immersive learning environments that promote critical thinking, creativity, and cooperation. Finally, the combination of science, technology, and innovation in education exemplifies constructivist ideas, allowing students to actively construct meaning and gain a greater understanding of the universe.

1. **Science, Technology, and Innovation in Empowering Connectivism Learning**

Another important theory, connectivism, highlights the role of networks and connections in learning, highlighting technology's ability to ease access to knowledge and expertise (Siemens, 2005). Connectivism is a learning theory that emphasizes the role of networks and connections in the learning process (Siemens 2005). According to this theory, learning occurs when individuals, information, and technology link, allowing learners to access and exchange knowledge. In today's digital context, connectivism emphasises technology's ability to enhance learning by offering access to large amounts of knowledge, expertise, and varied perspectives.

The key ideas of connectivism are networked learning, distributed knowledge, and technology-mediated learning. Networked learning highlights the value of connecting people and information, allowing students to access and exchange knowledge (Siemens, 2005). dispersed knowledge is the concept that knowledge is dispersed across networks and that learners can access and contribute to it via connections (Downes, 2007). Technology-mediated learning emphasises the importance of technology in supporting connectivist learning by allowing students to access information, connect with others, and participate in online communities (Kop & Hill, 2008).

Connectivist principles are applicable in a variety of educational settings, including online learning environments, social media platforms, and Massive Open Online Courses (MOOCs). Learners, for example, can participate in online forums, interact with experts, and access resources, demonstrating how technology can help foster connectivist learning (Siemens, 2005). Using connectivist concepts, educators can construct learning environments that promote collaboration, information sharing, and critical thinking.

Recent research has investigated the use of connectivist concepts in a variety of contexts, including personal learning networks, social media in education, and MOOCs. Personal learning networks allow students to interact with others and access resources to help them learn (Rajagopal et al., 2012). Social media platforms can aid in connectivist learning by allowing students to connect with others, share knowledge, and participate in online communities (Perez et al, 2023). MOOCs can promote connectivist learning by allowing students to connect with others and access materials on a broad scale (Kop et al., 2011).

As such, connectivism offers a useful paradigm for understanding the function of networks and connections in learning, emphasising technology's ability to ease access to knowledge and expertise. Educators can use connectivist concepts to construct learning settings that foster the development of critical thinking, cooperation, and information-sharing abilities.

**Educational Transformation: Challenges and Opportunities**

Educational transformation through technology integration has the potential to improve learning experiences, but it also raises issues that must be addressed. Personalised learning, enabled by technology, may respond to individual students' needs and skills, increasing student engagement and outcomes (Baird et al., 2017). However, problems about equality and access arise, as not all students may benefit equally from technology-enhanced learning (Gorski, 2005). Individual students' needs and talents can be met through personalised learning, which is made possible by technology. However, it raises questions regarding equity, access, and teacher preparation (Baird et al., 2017). Accessibility and inclusion are crucial factors, as technology has the potential to bridge and aggravate existing divides (Gorski, 2005).

Teacher training and capacity building are critical for successful technology integration, necessitating continuing support and professional development (Law and Chow, 2008). For example, pupils from low-income families or those with impairments may face challenges to using technology, potentially increasing existing disparities.

Teacher training and capacity building are critical for successful technology integration, necessitating continuing support and professional development (Law and Chow, 2008). Teachers must be trained with the skills and expertise to use technology to improve teaching and learning, rather than just as a tool for delivery. This necessitates a transition in educational methodologies, from traditional teacher-centred methods to more student-centred and collaborative ones.

Furthermore, accessibility and inclusion are important factors in instructional technology. Depending on how it is conceived and deployed, technology has the potential to bridge or worsen existing disparities. For example, digital tools can be created to be accessible to students with disabilities, or they can introduce new hurdles if not appropriately developed. As a result, when designing and implementing instructional technology, accessibility and diversity must be prioritised.

AI-powered personalised learning systems are revolutionising education by analysing student data to tailor content delivery, addressing diverse learning needs and styles more effectively. These systems use advanced algorithms to create customised learning paths, providing real-time feedback and assessment. By identifying individual learning styles, strengths, and weaknesses, AI-powered platforms can recommend specific lessons, activities, and resources that cater to each student's unique needs (UNESCO, 2021). Mo (2025) also found that ChatGPT has the potential to transform the education ecosystem by enhancing personalised learning, improving student engagement, and increasing accessibility to educational resources.

AI-powered personalised learning systems have shown promising results in improving student engagement and academic performance. By adapting content to individual learning needs, AI helps students learn at their own pace, reinforcing concepts they struggle with and accelerating through familiar content. This tailored approach not only boosts student confidence but also fosters a deeper understanding of the material, ultimately leading to better learning outcomes (Chiu et al. 2024).

AI-powered tools also facilitate communication and learning for students with disabilities, offering customizable features like text-to-speech, closed captioning, or braille support. This makes education more accessible and inclusive for everyone. By providing equal opportunities for students with disabilities to participate and succeed, AI-powered tools promote diversity and equity in education (Chen & Singh, 2025).

Predictive analytics helps identify students at risk of falling behind or dropping out, enabling timely interventions and support. Analysing student data, educators can set realistic goals and develop targeted strategies to improve student outcomes. This data-driven approach allows educators to make informed decisions, allocate resources effectively, and provide personalised support to students who need it most (Kim, 2019; Adenle et al., 2023).

Despite the opportunities presented by Science, Technology, and Innovation (STI) in education, Roshanaei et al. (2023) noted that several challenges hinder its effective integration. One major concern is data privacy, where the collection and analysis of student data raises concerns about potential misuse and reinforcement of existing educational disparities. These concerns need to be addressed critically to ensure that STI benefits all students without compromising their privacy or widening existing gaps.

Another significant challenge, according to Roshanaei et al. (2023), is the digital divide, which refers to the unequal access to technology and digital resources among students from different socio-economic backgrounds. Ensuring equitable access to STI opportunities is crucial to prevent exacerbating existing inequalities and to provide all students with the opportunity to benefit from these innovations.

Furthermore, Roshanaei et al. (2023) averred that those biases in AI algorithms pose a significant challenge to the effective integration of STI in education. AI algorithms are only as good as the data they are trained on, and if these datasets do not reflect diverse experiences and viewpoints, there is a risk of perpetuating biases. Therefore, it is essential to ground AI algorithms in diverse and inclusive datasets to ensure that they promote equity and fairness in education.

Therefore, acknowledging and addressing these challenges, educators and policymakers can work towards harnessing the potential of STI to create more inclusive, effective, and equitable learning environments for all students.

Finally, educational change through technology integration necessitates a critical assessment of the problems and opportunities it brings. Educators and policymakers may use technology to improve learning experiences and outcomes for all children by focusing on equity, access, teacher training, and accessibility.

**Case Studies and Best Practices**

Several case studies illustrate the successful implementation of science, technology, and innovation in education.

1. **The Khan Academy**

The Khan Academy in 2008, and it has transformed global access to quality education. Khan Academy has helped millions of students around the world by providing free, high-quality educational tools. The platform's scalability, customisation, and accessibility have made it a role model for using technology in education. Similar projects in Nigeria have the potential to improve access to quality education, particularly in local regions. The Khan Academy has used technology to offer free, high-quality educational tools to millions of students worldwide (Khan, 2012).

1. **Bridge to Enter Advanced Mathematics (BEAM)**

Similarly, the Bridge to Enter Advanced Mathematics initiative supports underserved children in Mathematics using technology-enhanced instruction (BEMA,2020). The Bridge to Enter Advanced Mathematics (BEAM) initiative uses technology-enhanced training to empower underrepresented children in Mathematics, proving the power of targeted interventions to close educational gaps (BEAM, 2020). BEAM supports traditional curriculum by providing interactive tools and internet resources, as well as encouraging students to feel a sense of community. In Nigeria, where Mathematics and Science Education confront considerable problems, BEAM's methodology might help influence initiatives for supporting underrepresented pupils and promoting STEM education.

1. **Duolingo’s Gamifying Language Learning**

Duolingo, a language-learning website, has successfully used technology to make language learning more enjoyable and accessible. With over 300 million users worldwide, Duolingo's gamified approach and adaptive learning algorithms have revolutionised language learning. In Nigeria, where language acquisition is critical for cultural preservation and global communication, Duolingo's model can inspire new ways of language teaching.

1. **Readiness of Vietnamese High Schools for Digital Transformation and Its Influencing Factors**

The study on the Readiness of Vietnamese High Schools for Digital Transformation and Its Influencing Factors by Nguyen et al. (2022) found that Vietnamese high schools have a moderate level of readiness for digital transformation. The study identified several influencing factors, including school leadership, teacher capacity, infrastructure, and resources, that significantly impact the readiness of high schools for digital transformation. The findings suggest that schools with strong leadership, adequate infrastructure, and capable teachers are better equipped to implement digital transformation. The study's results provide insights into the current state of digital readiness in Vietnamese high schools and highlight the need for targeted interventions to support schools in their digital transformation journey, ultimately enhancing the quality of education and preparing students for the digital age.

These case studies highlight how technology can alter education, improve access, and promote equity. Using technology and innovation, Nigerian educators and policymakers can create targeted interventions to address local concerns and improve educational performance.

**Conclusion**

In conclusion, science, technology, and innovation have the potential to transform education, enhancing learning outcomes and preparing students for the demands of the 21st century. However, challenges and opportunities must be carefully considered, and policymakers, educators, and researchers must work together to harness the power of science, technology, and innovation for educational transformation.

Future research should focus on key areas such as AI-powered learning analytics, augmented reality, blockchain technology, and innovative approaches to STEM education. Investigating the impact of emerging technologies on learning outcomes and educational systems can unlock new possibilities for enhancing learning outcomes and promoting national development. The future of education lies in leveraging science, technology, and innovation to drive national development, and policymakers, educators, and researchers must prioritise innovation and technology integration, investing in infrastructure, teacher training, and research. This will create a more effective, inclusive, and sustainable education system that prepares students for success in the 21st century.

**Future Directions and Recommendations**

As the world evolves, new trends such as AI-powered learning analytics, augmented reality, and blockchain technology have the potential to alter education. To capitalise on the benefits of developing technologies, policymakers, educators, and researchers must prioritise innovation and technological integration.

**Supporting Innovation and Technology Integration**

Policymakers play a crucial role in supporting innovation and technology integration in education. This can be achieved through:

1. **Investing in infrastructure:** Developing robust digital infrastructure to support the integration of emerging technologies (OECD, 2020).
2. **Teacher training:** Providing educators with the necessary skills and knowledge to effectively integrate technology into their teaching practices (Law & Chow, 2008).
3. **Research and development:** Encouraging research and development in education technology to explore new possibilities and address existing challenges (Spector et al., 2014).

To harness the full potential of Science, Technology, and Innovation (STI) in education, a multi-stakeholder approach is necessary. Students, teachers, and researchers should engage in lifelong learning, leveraging emerging technologies to enhance knowledge and skills while prioritising critical thinking and interdisciplinary approaches. Meanwhile, policymakers, government, and society should step up investment in education infrastructure, support teacher training, and promote inclusive access to technology, ensuring equitable opportunities for all. Additionally, parents should encourage curiosity, creativity, and digital literacy in children, foster a growth mindset, and support educators in their vital role, ultimately creating a collaborative ecosystem that promotes educational transformation and benefits all stakeholders.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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