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# The Roles of Emerging Technology in Chemistry Teaching and Learning for a Sustainable Development

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## A B S T R A C T

The discipline of science education, and more specifically the teaching and learning of chemistry, has been greatly impacted by the rapid advancement of technology. Teaching chemistry through the use of information and communication technology ICT and emerging technological developments is becoming more and more common. A paradigm shift in the educational system has resulted from the effective integration of technology in instruction processes, this has greatly improved learning outcomes by making the teaching and learning process dynamic, fascinating, interactive, and engaging. The relevance of integrating emerging technologies into chemistry teaching and learning is the main focus of this paper. Attention was drawn to the functions of emerging technologies, which are in high demand right now. It also covers the significance of providing chemistry teachers and students with up-to-date technology skills as well as the continuous maintenance and improvement of those abilities to ensure a sustainable future. The researchers discussed how emerging technologies such as biotechnology, nanotechnology, information, and communication technology could be incorporated into chemistry curricula in secondary schools for a sustainable future. This paper also focuses on the expectation pattern of emerging technology and how it could be used to sustain the future. Relevant literature was reviewed in the areas of science education, chemistry learning, emerging technology, and education for a sustainable future.

## 1. INTRODUCTION

The rapid advancement of technology has profoundly transformed the education sector, revolutionizing both teaching and learning processes. Digital tools and platforms, such as online courses, virtual classrooms, and educational apps, have made learning more accessible, personalized, and interactive (Kokkinos, 2024). Students can now access a wealth of information and resources from anywhere in the world, fostering a more inclusive and diverse learning environment. Additionally, technologies like artificial intelligence and machine learning are being integrated into educational systems to provide tailored learning experiences, assess student performance in real time, and identify areas where additional support is needed (Bizami *et al.,* 2023). This technological evolution not only enhances the quality of education but also equips students with the digital literacy skills essential for success in the modern world (Tapalova & Zhiyenbayeva, 2022).

The integration of emerging technology in chemistry education is crucial for a sustainable future for several key reasons such as the provision of advanced technologies including virtual labs and simulations, providing students with hands-on experience and a deeper understanding of complex chemical processes without the need for physical resources, reducing waste and exposure to hazardous substances. Digital tools are another factor that enables the exploration of green chemistry principles, promoting environmentally friendly practices and the development of sustainable materials and processes. Technologies like artificial intelligence and big data analytics facilitate cutting-edge research and innovation, allowing students to tackle global challenges such as climate change, renewable energy, and pollution control more effectively. By equipping students with the skills and knowledge to leverage these technologies, chemistry education can foster a new generation of scientists and innovators dedicated to creating sustainable solutions for a healthier planet (Nizetic *et al.,* 2020; Acosta-Castellanos & Queiruga-Dios, 2022).

## 2. LITERATURE REVIEW
### 2.1. Concept of emerging technology

Emerging technologies are innovative tools, methods, or devices that are currently under development or in the early stages of deployment, which are expected to significantly impact society, industry, and the economy (Babadi *et al.,* 2022; Rani *et al.,* 2021; Javaid *et al.,* 2022). These technologies typically offer new capabilities, improve existing processes, or create entirely new industries and opportunities. Examples of emerging technologies are artificial intelligence and machine learning, blockchain technology, internet of things (IoTs), 5G technology, quantum computing, augmented reality (AR) and virtual reality (VR), biotechnology, renewable energy technology, robotic and automation and nanotechnology (Tsaramirsis *et al.,* 2022).

Artificial intelligence (AI) is a field of computer science that focuses on creating systems capable of performing tasks that typically require human intelligence, such as understanding natural language, recognizing patterns, solving problems, and making decisions (Korteling *et al.,* 2021). Machine learning (ML), a subset of AI, involves training algorithms on large datasets to enable them to learn from patterns and improve their performance over time without being explicitly programmed. Through processes like supervised, unsupervised, and reinforcement learning, ML models can make predictions, classify data, and uncover insights, driving advancements in areas such as healthcare, finance, and autonomous vehicles. Together, AI and ML are transforming industries by automating complex tasks and providing intelligent solutions to challenging problems.

Blockchain technology is a decentralized digital ledger system that securely records transactions across a network of computers. It operates through a series of blocks, each containing a list of transactions, which are linked together in chronological order. Each block is secured using cryptographic techniques, ensuring that once data is recorded, it cannot be altered or deleted without altering all subsequent blocks, thus making the blockchain tamper-resistant. This technology underpins cryptocurrencies like Bitcoin but also has broader applications in areas such as supply chain management, voting systems, and secure data sharing, offering transparency, security, and decentralization (Javaid *et al.*, 2022).

The Internet of Things (IoT) refers to the network of interconnected physical devices that collect and exchange data through the Internet. These devices, which range from everyday household items like smart thermostats and wearable fitness trackers to industrial machines and city infrastructure, are embedded with sensors, software, and other technologies. IoT enables these devices to communicate with each other and with central systems, allowing for real-time monitoring, automation, and improved efficiency across various applications. Integrating IoT into daily life and industries promises to enhance convenience, optimize resource use, and create new opportunities for innovation (Rehan, 2023).

Five (5G) technology presents the fifth generation of mobile networks, promising significantly faster data speeds, lower latency, and increased connectivity compared to its predecessors (Shafique *et al.*, 2020). It operates on higher-frequency radio waves, allowing for more data to be transmitted at once, thereby supporting more devices and enabling faster response times. 5G's enhanced capabilities are expected to revolutionize various industries, from healthcare and manufacturing to transportation and entertainment, by enabling innovations like remote surgery, autonomous vehicles, and immersive virtual reality experiences, with its potential to support the Internet of Things (IoT) on a massive scale and facilitate real-time data processing, 5G is poised to drive unprecedented levels of connectivity and technological advancement globally.

According to Wong (2022), quantum computing harnesses principles of quantum mechanics to process information in fundamentally different ways than classical computing. At its core, quantum computers use quantum bits or qubits, which can exist in multiple states simultaneously by adopting the phenomena of superposition and entanglement. This capability allows quantum computers to solve certain types of complex problems much faster than classical computers. Applications of quantum computing range from cryptography (that is the practice and study of techniques for secure communication in the presence of third parties, involving encoding and decoding messages to ensure privacy and integrity) and optimization tasks (that is finding the best solution from a set of possible solutions to maximize or minimize a particular objective function, often under constraints or conditions) to drug discovery and materials science, promising transformative impacts across industries by tackling challenges that are currently beyond the reach of classical computing power (Wong, 2022; Nofer *et al.*, 2023).

Virtual reality (VR) and augmented reality (AR) are immersive technologies that alter perception and interaction with the physical world (Fan *et al.*,2022). VR creates entirely virtual environments that users can interact with through specialized headsets or devices, enabling experiences ranging from simulated worlds to training simulations and entertainment. On the other hand, AR overlays digital content onto the real world, typically viewed through smartphones, glasses, or heads-up displays. AR enhances real-world environments by adding computer-generated elements such as information, graphics, or animations, enhancing tasks like navigation, education, and gaming. Both VR and AR technologies are transforming industries by offering new ways to experience and interact with digital and physical spaces,

driving innovation in fields from healthcare and education to retail and entertainment (Fan *et al.*, 2022).

Biotechnology encompasses the use of biological systems, organisms, or their components to develop products or processes that improve human life and the environment. It integrates disciplines like genetics, molecular biology, and biochemistry to manipulate living organisms or biological systems for practical applications. Biotechnological advancements range from pharmaceuticals and medical treatments, such as gene therapies and vaccines, to agricultural improvements like genetically modified crops and sustainable biofuels. This interdisciplinary field continues to expand, driven by innovations in genetic engineering, bioprocessing, and bioinformatics, with the potential to address global challenges in healthcare, food security, and environmental sustainability (Fabris *et al.*, 2020).

Renewable energy technology refers to methods and systems that harness naturally replenishing resources to generate electricity or provide heat, offering sustainable alternatives to fossil fuels. Renewable energy technologies include solar photovoltaics (PV), wind turbines, hydroelectric power, biomass energy, and geothermal systems. Solar PV systems convert sunlight into electricity, while wind turbines capture kinetic energy from the wind to generate power. Hydroelectric dams harness the gravitational force of flowing water, and biomass utilizes organic materials for energy production. Geothermal technology extracts heat from the Earth's core for heating and electricity generation. Renewable energy technologies play a crucial role in mitigating climate change by reducing greenhouse gas emissions, promoting energy independence, and fostering economic growth through job creation and technological innovation (Jain, 2020).

Robotics and automation involve the use of mechanical, electrical, and computer systems to create machines that can perform tasks autonomously or semi-autonomously, often replacing or augmenting human labor. Robotics encompasses the design, construction, operation, and use of robots across various industries, from manufacturing and healthcare to space exploration and entertainment. Automation, on the other hand, refers to the application of technology to automate processes or tasks traditionally performed by humans, using systems like robotic arms, automated assembly lines, and software algorithms. Together, robotics and automation aim to increase efficiency, precision, and safety in operations, reduce costs, and enable new capabilities in industries worldwide, driving advancements in artificial intelligence, sensors, and control systems.

Nanotechnology involves manipulating matter on an atomic or molecular scale, typically ranging from 1 to 100 nanometers Sahu *et al.* (2023) to create materials, devices, and systems with unique properties and functionalities. It spans disciplines such as physics, chemistry, biology, and engineering, enabling the design and manufacture of nanoscale structures and devices. Applications of nanotechnology include nanomedicine for targeted drug delivery and imaging, nanoelectronics for smaller and more efficient devices, nanomaterials for lightweight and strong materials, and environmental applications like water purification and pollution control. Nanotechnology holds promise for revolutionizing industries by offering unprecedented control over materials and processes, potentially addressing challenges in healthcare, energy, electronics, and environmental sustainability (Sahu *et al.*, 2023).

## 2.2. Emerging technologies for enhancing chemistry teaching and learning

As the world advances towards a sustainable future, the integration of emerging technologies into education, particularly in the field of chemistry, becomes increasingly vital. These technologies not only enhance the learning experience but also equip students with the necessary skills to tackle future environmental and scientific challenges. Virtual and

augmented reality offer immersive experiences that can transform abstract chemical concepts into tangible, visual phenomena. VR allows students to explore molecular structures and chemical reactions in a three-dimensional space, providing a deeper understanding of complex subjects. AR can overlay digital information onto the physical world, enabling interactive experiments without the need for expensive laboratory equipment or hazardous materials. AI and machine learning can personalize the learning experience by adapting to individual students' needs. Intelligent tutoring systems can provide instant feedback, identify areas of struggle, and suggest targeted exercises. Furthermore, AI can assist in predicting chemical reactions and outcomes, fostering a deeper understanding of chemistry through simulation and analysis.

Online labs and remote experimentation platforms allow students to conduct experiments virtually, providing access to a wide range of chemical processes and phenomena. These platforms can simulate real-world lab environments, making it possible for students to practice their skills safely and cost-effectively. This is particularly beneficial for institutions with limited resources or those located in remote areas. Incorporating gamification into chemistry education can make learning more engaging and enjoyable. Interactive simulations and educational games can motivate students to explore chemical principles and solve problems creatively. By turning complex topics into interactive challenges, students can better grasp difficult concepts and retain information more effectively. Also,3D printing technology can be used to create models of molecular structures, laboratory equipment, and other educational tools. These physical models can help students visualize and understand spatial relationships and molecular geometry, which are often difficult to grasp through traditional methods. Additionally, 3D printing promotes hands-on learning and experimentation.

Utilizing data analytics and big data in chemistry education can provide insights into student performance and learning patterns. By analyzing large sets of data, educators can identify trends, customize teaching strategies, and improve educational outcomes. Big data can also facilitate research and innovation in chemistry by providing comprehensive datasets for analysis and experimentation. Cloud computing enables collaborative learning and resource sharing among students and educators. Cloud-based platforms can host virtual labs, educational software, and databases, making them accessible from anywhere at any time. This fosters a collaborative learning environment where students can work together on projects, share findings, and access up-to-date resources. The adoption of emerging technologies in chemistry education holds immense potential for creating a sustainable future. By leveraging VR/AR, AI, online labs, gamification, 3D printing, data analytics, and cloud computing, educators can enhance the learning experience, make chemistry more accessible, and prepare students to address future scientific and environmental challenges. Integrating these technologies into the curriculum not only improves educational outcomes but also inspires the next generation of chemists to innovate and contribute to a sustainable world.

## 3. METHOD

The researchers of this work adopted a systematic literature review technique of thirty relevant journal articles, and proceedings, to obtain information and insights using ResearchGate, ProQuest, Web of Science, Google Scholar, and repositories of academic institutions. To support the researcher's argument, the study extensively references other studies and research articles, classifying them according to the areas covered, such as emerging technology in education, emerging technology and chemistry teaching, the

significance of integrating emerging technology in Nigerian chemistry curriculum, the difficulties and opportunities associated with the integration of emerging technology. The paper's assertions regarding the advantages, difficulties, and approaches related to introducing technology into education and coordinating educational activities with a sustainable future are reinforced by the inclusion of these sources. This extensive literature review highlights the paper's dependence on prior research to provide a strong basis for understanding and insightful analysis of emerging technologies and their role in fostering a sustainable future in the context of education.

## 4. RESULTS AND DISCUSSION
### 4.1. Emerging technologies in education

In the context of education, "emerging technologies" refer to innovative tools, platforms, and methodologies that are newly developed or recently becoming more widely adopted and have the potential to enhance teaching and learning experiences significantly (Ciarli *et al.,* 2021). These technologies often leverage advancements in fields such as information technology, artificial intelligence, and digital media to create more interactive, personalized, and efficient educational environments. Examples of emerging technologies in education include virtual and augmented reality, artificial intelligence and machine learning, big data analytics, online and blended learning platforms, educational apps, and digital collaboration tools. These technologies can transform traditional educational practices, making learning more accessible, engaging, and effective for students and educators alike (Haleem *et al.,* 2022).

Onyema (2020) carried out a study on the incorporation of emerging technologies into the teaching and learning process in Nigeria. The findings indicate that most participants concur that incorporating emerging technologies into the teaching and learning process modernizes and inspires education, increases inclusivity, and facilitates the attainment of learning objectives. Emerging technologies for teaching and learning science encompass a range of innovative tools and methodologies that enhance engagement, understanding, and accessibility. These include virtual and augmented reality simulations that provide immersive experiences, enabling students to explore complex scientific concepts in interactive environments. Additionally, artificial intelligence and machine learning applications offer personalized learning experiences by analyzing student data and adapting content delivery accordingly. Robotics and Internet of Things (IoT) devices facilitate hands-on experimentation and data collection, fostering inquiry-based learning and real-world applications. These technologies not only make science education more dynamic and inclusive but also prepare students for future careers in STEM (Science, Technology, Engineering, and Mathematics) fields by emphasizing critical thinking, problem-solving, and technological literacy.

### 4.2. Emerging technology and chemistry teaching and learning

Emerging technologies can revolutionize chemistry education by offering interactive and dynamic learning experiences. Virtual reality (VR) and augmented reality (AR) simulations allow students to visualize molecular structures in three dimensions, explore chemical reactions in real time, and conduct virtual experiments safely and efficiently (Fombona-Pascual *et al.,* 2022). Artificial intelligence (AI) can personalize learning by analyzing student performance and adapting instructional content to individual learning styles and paces. Nanotechnology demonstrations and simulations can illustrate concepts at the atomic and molecular scale, enhancing understanding of materials and their properties. Furthermore, online platforms and mobile applications provide access to vast databases, digital textbooks,

and collaborative tools, facilitating remote learning and fostering global knowledge sharing among students and educators (Haleem *et al.,* 2022). By leveraging these technologies, chemistry education becomes more engaging, accessible, and aligned with the evolving demands of scientific research and industry applications.

Chiu (2021) conducted a study on the pedagogy of emerging technology in chemical education during the era of digitization and artificial intelligence. The researcher classified emerging technology for teaching various chemistry topics as virtual reality, augmented reality, mixed reality, artificial intelligence, robotics, eye tracking, and learning analytics, the researcher suggested that technological advancement should also be used to facilitate chemistry learning in inclusive education (Chiu, 2021). The role of emerging technology in chemistry teaching and learning is pivotal for fostering a sustainable future. These technologies, such as virtual and augmented reality simulations, artificial intelligence for personalized learning pathways, and advanced data analytics, enable students to grasp complex chemical concepts more effectively and apply them to real-world challenges in sustainability (Chiu, 2021). By integrating these tools, educators can emphasize the importance of green chemistry principles, renewable energy sources, and environmental stewardship. Hands-on experiences facilitated by robotics and IoT devices allow students to experiment with sustainable materials and processes, preparing them to innovate and contribute to solutions that address global environmental concerns. Ultimately, leveraging emerging technologies in chemistry education empowers the next generation of scientists and engineers to develop sustainable practices and technologies essential for a thriving and resilient future.

### 4.3. Importance of integrating emerging technology in Nigerian chemistry curriculum

Integrating emerging technology into the Nigerian chemistry curriculum is crucial for advancing towards a sustainable future (Grace *et al.,* 2024). These technologies, including virtual and augmented reality simulations, artificial intelligence for data analysis and modeling, and advancements in nanotechnology and green chemistry, offer tools to address environmental challenges and promote sustainable practices, by exposing students to these innovations, educators can inspire a mindset focused on innovation and problem-solving in areas such as clean energy development, pollution control, and resource conservation (Oriji & Nnadieze, 2023). This integration not only prepares students for careers in a technologically-driven world but also equips them with the skills to contribute meaningfully to sustainable development initiatives in Nigeria, ensuring environmental stewardship and economic resilience for future generations.

### 4.4. Challenges and prospect of integrating emerging technology in Nigerian chemistry curriculum

Integrating emerging technology into the Nigerian chemistry curriculum for sustainable development faces challenges such as limited access to reliable internet and electricity in some regions, high costs associated with acquiring and maintaining technology infrastructure, and the need for specialized training for educators (Akpomi *et al.,* 2020). These obstacles may hinder widespread adoption and equitable access across the country. However, the prospects are substantial: leveraging technologies like virtual and augmented reality, artificial intelligence, and advanced data analytics can enhance understanding of sustainable chemistry principles, promote innovative solutions to environmental challenges, and prepare students for careers in emerging fields such as green chemistry and renewable energy. By overcoming these challenges through strategic investments in infrastructure and training,

Nigeria can empower its youth to drive forward sustainable development initiatives, fostering economic growth and environmental stewardship for future generations.

### 4.5. Addressing the challenges associated with integrating emerging technology in Nigerian chemistry curriculum

Integrating emerging technology into the Nigerian chemistry curriculum presents various challenges that can be addressed through a multifaceted approach.

Investing in modern laboratories and digital infrastructure to support the use of emerging technologies.

Ensuring schools have consistent and high-speed internet access to utilize online resources and tools.

Providing regular training and workshops for teachers on the latest technological tools and their applications in teaching chemistry.

Establishing a support system for teachers to assist with troubleshooting and integrating technology into their lessons.

Incorporating emerging technologies and their applications into the chemistry curriculum to make it more relevant and engaging.

Allowing flexibility in the curriculum to adapt to technological advancements and emerging educational tools.

Ensuring that schools have access to the latest educational software, virtual labs, and interactive simulations.

Developing platforms for sharing educational resources and best practices among teachers and schools.

Advocating for government policies that support the integration of technology in education and allocate funding for necessary resources.

Encouraging collaborations between schools, technology companies, and NGOs to provide resources and training.

Using interactive and multimedia tools to make chemistry lessons more engaging and understandable for students.

Ensuring that all students, regardless of socioeconomic status, have access to the necessary technological tools and resources.

Implementing systems for regular assessment and evaluation of the integration process to identify challenges and areas for improvement.

Creating channels for teachers, students, and parents to provide feedback on the use of technology in the curriculum.

Encouraging the formation of teacher networks and professional learning communities to share experiences and strategies.

Promoting collaborative projects and activities that leverage technology to enhance learning and problem-solving skills.

### 4.6. Discussion

Emerging technologies are characterized by their novelty, potential for significant impact across various domains, and rapid evolution (Erwin, 2021). They often introduce disruptive innovations that challenge existing norms and practices, driven by scientific research, engineering, and technological development advancements. These technologies typically exhibit features such as high innovation potential, scalability, and the ability to address pressing societal or environmental challenges. They may also involve interdisciplinary approaches, combining insights and methods from diverse fields to achieve breakthroughs.

Emerging technologies are marked by ongoing research and development efforts, with their adoption and integration into mainstream applications influenced by factors like regulatory frameworks, economic feasibility, and societal acceptance (Erwin, 2021; Zamani *et al.,*2022).

Emerging technologies play a crucial role in advancing human civilization by offering innovative solutions to complex global challenges. They drive economic growth through new industries and job creation, enhance the quality of life by improving healthcare, education, and communication systems, and promote sustainability by offering cleaner energy sources and efficient resource management (Goel & Vishnoi, 2022). These technologies also foster scientific exploration and discovery, pushing the boundaries of human knowledge and capabilities. Moreover, they enable societies to adapt and respond to rapid changes, such as demographic shifts and environmental pressures, while paving the way for a more interconnected and resilient world. Embracing and responsibly deploying emerging technologies can lead to transformative benefits, empowering individuals and communities globally to effectively address current and future needs (Suklabaidya, 2024).

Emerging technologies are at the forefront of innovation, shaping the future by transforming industries and society through advanced capabilities and novel applications (Ciarli *et al.,* 2021). Emerging technologies are crucial for sustainable development as they offer innovative solutions to mitigate environmental impact, enhance resource efficiency, and promote renewable energy adoption. By enabling smarter infrastructure, precision agriculture, and clean technologies, these advancements can help societies achieve long-term economic growth while preserving the planet's natural resources for future generations (Appio *et al.,* 2021; Ciarli *et al.,* 2021).

## 5. CONCLUSION

In conclusion, the integration of emerging technologies into the teaching and learning of chemistry has had a transformative impact on science education, making the learning process more dynamic, interactive, and engaging. The paper emphasizes the significance of equipping both teachers and students with up-to-date technological skills, ensuring the continuous enhancement and sustainability of these skills for future use. The adoption of technologies like biotechnology, nanotechnology, and ICT in chemistry curricula is highlighted as crucial for fostering a sustainable future. The researchers underscore that the effective implementation of these technologies in education is key to improving learning outcomes and promoting sustainability in the field.

## 6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

## 7. REFERENCES

Acosta-Castellanos, P.M., and Queiruga-Dios, A. (2022). From environmental education to education for sustainable development in higher education: A systematic review. *International Journal of Sustainability in Higher Education, 23*(3), 622-644.

Akpomi, M.E., Dambo, B.I., Ikpesu, O.C., Singer, S.A., Wokocha, K.D., Ben-George, I., and Babalola, J.O. (2020). Educational, scientific and technological innovations for sustainable development in Nigeria. *World Journal of Entrepreneurial Development Studies, 5*(1), 50-63.

Appio, F.P., Frattini, F., Petruzzelli, A.M., and Neirotti, P. (2021). Digital transformation and innovation management: A synthesis of existing research and an agenda for future studies. *Journal of Product Innovation Management, 38*(1), 4-20.

Babadi, A.A., Rahmati, S., Fakhlaei, R., Barati, B., Wang, S., Doherty, W., and Ostrikov, K.K. (2022). Emerging technologies for biodiesel production: Processes, challenges, and opportunities. *Biomass and Bioenergy, 163*, 106521.

Bizami, N.A., Tasir, Z., and Kew, S.N. (2023). Innovative pedagogical principles and technological tools capabilities for immersive blended learning: A systematic literature review. *Education and Information Technologies, 28*(2), 1373-1425.

Chiu, W.K. (2021). Pedagogy of emerging technologies in chemical education during the era of digitalization and artificial intelligence: A systematic review. *Education Sciences, 11*(11), 709.

Ciarli, T., Kenney, M., Massini, S., and Piscitello, L. (2021). Digital technologies, innovation, and skills: Emerging trajectories and challenges. *Research Policy, 50*(7), 104289.

Erwin, D.H. (2021). A conceptual framework of evolutionary novelty and innovation. *Biological Reviews, 96*(1), 1-15.

Fabris, M., Abbriano, R.M., Pernice, M., Sutherland, D.L., Commault, A.S., Hall, C.C., Labeeuw, L., McCauley, J.I., Kuzhiuparambil, U., Ray, P., Kahlke, T., and Ralph, P.J. (2020). Emerging technologies in algal biotechnology: Toward the establishment of a sustainable, algae-based bioeconomy. *Frontiers in Plant Science, 11*, 279.

Fan, X., Jiang, X., and Deng, N. (2022). Immersive technology: A meta-analysis of augmented/virtual reality applications and their impact on tourism experience. *Tourism Management, 91*, 104534.

Fombona-Pascual, A., Fombona, J., and Vázquez-Cano, E. (2022). VR in chemistry, a review of scientific research on advanced atomic/molecular visualization. *Chemistry Education Research and Practice, 23*(2), 300-312.

Goel, R.K., and Vishnoi, S. (2022). Urbanization and sustainable development for inclusiveness using ICTs. *Telecommunications Policy, 46*(6), 102311.

Grace, T.J., Abiodun, G.M., Sahdat, A.S., Rebecca, O., and Ebunoluwa, R.O. (2024). Harnessing science education for future transformation in Nigeria. *Educational Perspectives, 12*(1), 255-267.

Haleem, A., Javaid, M., Qadri, M.A., and Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers, 3*, 275-285.

Jain, D. (2020). Renewable energy: Powering a safer future. *International Journal of Multidisciplinary Research in Science, Engineering and Technology, 1*(3), 429-434.

Javaid, M., Haleem, A., Singh, R.P., Suman, R., and Khan, S. (2022). A review of blockchain technology applications for financial services. *Bench Council Transactions on Benchmarks, Standards, and Evaluations, 2*(3), 100073.

Kokkinos, L. (2024). Revolutionizing education: The dynamic intersection of technology and learning. *International Journal of Multidisciplinary and Current Educational Research, 6*(1), 26-32.

Korteling, J.H., van de Boer-Visschedijk, G.C., Blankendaal, R.A., Boonekamp, R.C., and Eikelboom, A.R. (2021). Human-versus artificial intelligence. *Frontiers in Artificial Intelligence, 4*, 622364.

Nizetic, S., Solic, P., Gonzalez-De, D.L.D.I., and Patrono, L. (2020). Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future. *Journal of Cleaner Production, 274*, 122877.

Nofer, M., Bauer, K., Hinz, O., van der Aalst, W., and Weinhardt, C. (2023). Quantum computing. *Business & Information Systems Engineering, 65*(4), 361-367.

Onyema, E.M. (2020). Integration of emerging technologies in teaching and learning process in Nigeria: The challenges. *Central Asian Journal of Mathematical Theory and Computer Sciences, 1*(11), 35-39.

Oriji, A., and Nnadieze, G.C. (2023). Teachers' current technological challenges and expectations for futuristic learning in a knowledge-based economy. *Global Academic Journal of Humanities and Social Sciences, 5*(2), 96-111.

Rani, S., Mishra, R.K., Usman, M., Kataria, A., Kumar, P., Bhambri, P., and Mishra, A.K. (2021). Amalgamation of advanced technologies for sustainable development of smart city environment: A review. *IEEE Access, 9*, 150060-150087.

Rehan, H. (2023). Internet of Things (IoT) in smart cities: Enhancing urban living through technology. *Journal of Engineering and Technology, 5*(1), 1-16.

Sahu, M.K., Yadav, R., and Tiwari, S.P. (2023). Recent advances in nanotechnology. *International Journal of Nanomaterials, Nanotechnology and Nanomedicine, 9*(1), 15-23.

Shafique, K., Khawaja, B.A., Sabir, F., Qazi, S., and Mustaqim, M. (2020). Internet of things (IoT) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5G-IoT scenarios. *IEEE Access, 8*, 23022-23040.

Suklabaidya, S. (2024). Towards inclusive societies: Leveraging IoT for community development and education. *Novel Insights, 1*(1), 40-51.

Tapalova, O., and Zhiyenbayeva, N. (2022). Artificial intelligence in education: AIEd for personalized learning pathways. *Electronic Journal of E-Learning, 20*(5), 639-653.

Tsaramirsis, G., Kantaros, A., Al-Darraji, I., Piromalis, D., Apostolopoulos, C., Pavlopoulou, A., Alrammal, M., Ismail, Z., Buhari, S.M., Stojmenovic, M., Tamimi, H., Randhawa, P., Patel, A., and Khan, F.Q. (2022). A modern approach towards an industry 4.0 model: From driving technologies to management. *Journal of Sensors, 2022*(1), 5023011.

Wong, Y.K. (2022). Understanding the fundamentals of quantum computing. *International Journal of Computer Science Trends and Technology, 10*(2), 7-12.

Zamani, M., Yalcin, H., Naeini, A.B., Zeba, G., and Daim, T.U. (2022). Developing metrics for emerging technologies: Identification and assessment. *Technological Forecasting and Social Change, 176*, 121456.