Sustainable Education in the Digital Age: Leveraging Technological Advancements

Fahdilat Talatu Ahmed PhD
Department of Science Education
Al-Hikmah University Ilorin
ftahmed@alhikmah.edu.ng
08065706026

Olatunji Boye PhD
Department of Educational Technology
University of Ilorin, Ilorin, Nigeria
olatunjiboye@gmail.com
08066783301

Abstract

Sustainable education has emerged as an important model, aiming to equip learners with the knowledge and skills necessary for enhancing sustainable development. This review explores the impact of digital technologies on the sustainability of educational practices, looking into how digital tools and platforms can be harnessed to promote environmental stewardship, social equity, and economic viability. The paper examined recent literature on the integration of educational technology in various learning environments, highlighting innovative practices such as digital learning platforms, online collaborative tools, and adaptive learning systems. It also addresses the challenges and opportunities associated with the adoption of digital technologies in educational settings, with a focus on bridging the digital divide, ensuring inclusivity and accessibility in the educational process. Through an analysis of case studies and empirical data, this review underscores the transformative potential of technology in creating resilient educational frameworks that not only enhance learning outcomes but also contribute to the global sustainability. The findings underscore the necessity for policy-makers, educators, and technologists to collaborate in designing and implementing strategic initiatives that leverage technological advancements for sustainable education in the digital age.

Keywords: Technological advancements, Sustainable education, Digital learning platforms, Educational technology integration

Introduction

In education, the integration of technology has become an essential part of enhancing teaching and learning practices. The evolution of technology has revolutionized the traditional methods of teaching and learning, presenting both opportunities and challenges for educators. As educators maneuver this digital transformation, understanding their perspectives on technology integration is important for enhancing sustainable educational practices. Sustainab le education has gained

prominence as an essential model for equipping learners with the knowledge and skills necessary to promote sustainable development. This model of education seeks to address the interconnected challenges of environmental stewardship, social equity, and economic viability, all of which are key for achieving global sustainability goals (UNESCO, 2017)

Sustainable education transcends academic achievement, as it encompasses a holistic approach that nurtures intellectual curiosity, and empowers individuals to become agents of positive change (Hogan & O'Flaherty, 2022). Oluwagbemileke, (2024), stated that sustainable education in the digital age should prioritize the development of critical thinking, creativity, and problem-solving skills among learners. By harnessing the power of technology, educators can create immersive learning environments that stimulate curiosity and encourage exploration.

Integration of educational technology in various learning environments significantly transformed how education is delivered and experienced. This transformation is driven by the need to provide learners with the knowledge and skills necessary for promoting sustainable development. Sustainable education aims to promote social equity, economic viability, and technological advancements, which are pivotal in achieving these goals (Chankseliani & McCowan, 2020). One of the primary ways educational technology has been integrated into learning environments is through digital learning platforms. These platforms offer loads of resources and tools that facilitate both teaching and learning (Aljawarneh, 2020). For instance, e-learning platforms provide access to educational contents from anywhere in the world, breaking geographical barriers and ensuring that education is more accessible (Adeniyi, et al., 2024). These platforms often include interactive elements such as quizzes, forums, and multimedia resources, which enhance engagement and retention of educational information.

These platforms not only prepare learners for the challenges of the future but also cultivates a mindset of lifelong learning. Also, the advent of digital platforms and virtual learning environments has revolutionized the delivery of educational content, enabling real-time collaboration, personalized learning, and the seamless exchange of knowledge across the world (Alam & Mohanty, 2023). Online collaborative tools and adaptive learning systems have emerged as technological innovations that can enhance sustainable education (Cebrián, Palau, & Mogas, 2020). These digital tools and platforms offer unique opportunities for collaborative learning and personalizing learning experiences. Online collaborative tools facilitate real-time communication, file sharing, and collaborative document editing, enabling learners to work together perfectly regardless of their physical locations. Platforms like Google Workspace and Microsoft Office 365 have changed the way learners and educators collaborate on projects, assignments, and research. Using these tools can make group-based in-class activities, projects and assignments highly engaging for a diverse student body while also developing skills valued in the workplace (Lake, 2022). Online collaborative tools not only promote collaborative learning but also reduce the need for physical resources, contributing to environmental sustainability. Through collaboration and knowledge sharing, these tools can facilitate the development of critical thinking, problem-solving, and decision-making skills, which are important in addressing sustainability challenges (Straková & a Cimermanová, 2018). However, adaptive learning systems on the other hand, leverage artificial intelligence and machine learning algorithms to personalize learning experiences based on individual learners' needs, preferences, and abilities. These systems analyze learners' performance data, identify knowledge gaps, and dynamically adjust the content, pace, and delivery

methods to optimize learning outcomes (Almohammadi, Hagras, Alghazzawi, & Aldabbagh, 2017).

Artificial intelligence (AI), blockchain, and digital learning platforms, have the potential to revolutionize education by making it more accessible, inclusive, and effective. While the integration of technologies like artificial intelligence (AI) holds promise for tailoring educational experiences to individual learning styles and aptitudes (Onesi-Ozigagun et al, 2024), digital learning systems can also analyze student performance data, identify knowledge gaps, and adjust instructional strategies, ensuring balanced learning. The path toward sustainable education in the digital age encompasses not only the integration of technology into learning environments but also the adoption of practices that ensure the longevity and inclusive educational systems. Furthermore, sustainable education in the digital age necessitates a shift in pedagogical approaches, emphasizing critical thinking, problem-solving, and digital literacy skills. Educators and administrators must embrace innovative teaching methodologies that leverage digital tools while instilling values of social responsibility in learners (Shava, 2022).

Hence, the implementation of policies in facilitating digital literacy and access to technology in schools, is important for sustainable education (Falloon, 2020). Likewise, (Spiteri & Chang-Rundgren, 2020), highlighted the importance of teacher training programs in the effective use of educational technology, while (Azubuike, Adegboye, & Quadri, 2012), argue for the need to address the digital divide, ensuring that learners from all backgrounds have equal access to digital resources. Given this, the digital age presents both challenges and opportunities for sustainable education. On one hand, rapid technological advancements have enabled greater access to information, innovative learning tools, and collaborative platforms. However, these developments have also raised concerns about digital divides, environmental impact, and the need for digital literacy (Blazic & Blazic, 2020).

Problem Statement

A significant challenge for sustainable education is the digital divide, which remains a barrier to equitable access to educational technology. The digital divide refers to the gap between individuals who have access to modern information and communication technologies and those who do not. This gap is often influenced by socio-economic status, geographic location, and the availability of infrastructure (Calderón, 2018). For instance, while platforms like Google Classroom and Microsoft Teams offer substantial benefits for learning remotely and collaboration, their effectiveness is severely limited for learners in low-income or rural areas who lack reliable internet access and digital devices (Faturoti, 2022). This disparity not only sets backs the inclusivity and accessibility of education but also exacerbates existing educational inequalities, undermining the goal of sustainable education. Further, the implementation of adaptive learning systems, which use artificial intelligence to personalize learning experiences, introduces new challenges, as these systems require extensive data collection and analysis to tailor educational content to individual student needs. Without data security protocols, the risk of data breaches and misuse of sensitive information could erode trust in these technologies and limit their adoption in educational institutions (Anub, et al., 2024). Additionally, the cost of implementing and maintaining advanced educational technologies can be high for many educational institutions. Adaptive learning systems and online collaborative tools often require substantial initial investments in hardware, software,

and training (Grimus, 2020). For underfunded schools, particularly those in developing regions, these costs can be insurmountable, preventing them from benefiting from technological advancements. This financial barrier further entrenches educational disparities and limits the global reach of sustainable educational practices.

The educational sector in Africa, particularly in Nigeria, faces significant challenges in achieving sustainable and equitable access to quality education. Despite the rapid advancements in technology, many countries in Africa, including Nigeria, struggle to effectively integrate digital tools and resources into their educational systems (Martens, et al., 2020), hence, face a unique set of obstacles in achieving sustainable digital education. With a significant youth population and a demand for quality education, the country needs to leverage technological innovations to enhance access and quality (Olanrewaju & Afolabi, 2022). However, the digital divide, characterized by disparities in access to technology, infrastructure, and digital literacy, poses a significant barrier to equitable educational opportunities.

The problem statement for this study centers around the need to develop a comprehensive framework that will address the multifaceted challenges of sustainable digital education in Nigeria. This framework would encompass strategies for bridging the digital divide, strengthen digital literacy among educators and learners, and integrating technology into the curriculum in a manner that enhances learning outcomes while preserving cultural and contextual relevance.

Literature Review

Impact of Digital Technologies on the Sustainability of Educational Practices

The impact of digital technologies on the sustainability of educational practices is multifaceted, encompassing areas of accessibility, efficiency, and environmental footprint.

Accessibility is a component of sustainable education, ensuring that all learners, regardless of their socio-economic status or geographic location, have access to quality education, as it has the potential to change education by breaking down traditional barriers to learning (Takyi, Amponsah, Asibey, & Ayambire, 2019). For example, online learning platforms such as Coursera and edX offer free or low-cost courses from institutions, making quality education accessible to a global learner (Suresh & Srinivasan, 2020). These platforms allow learners from remote and underserved areas to access educational resources that would otherwise be unavailable to them. Further, access to blended learning could be the solution for providing education in the context of the 21st century, as the extensive integration of open educational resources, massive open online courses, social media and meeting has opened up the minds of those seeking knowledge, further enabling them to receive the necessary educational inputs, training and skills (Bordoloi, Das, & Das, 2021). Also, digital resources can be designed with accessibility features, such as closed captions, transcripts, and adjustable font sizes, ensuring that educational materials are inclusive and cater to diverse learning needs (Navarrete & Luján-Mora, 2018).

However, it is essential to recognize that the digital divide is a factor in the unequal access to digital technologies and the internet, which remains a significant challenge (Fang, et al., 2019). This divide can increase existing inequalities and perpetuate educational disparities, undermining

the sustainability of educational practices. Digital divide represents the gap between individuals who have access to modern information and communication technology (ICT) and those who do not. In Nigeria, this divide is a significant barrier to sustainable education, as it limits access to digital resources and online learning opportunities (Ogbo, Brown, Gant, & Sicker, 2021).

The COVID-19 pandemic further exacerbated this divide, which forced a shift to online education. The pandemic revealed the stark disparities in digital access and called for a paradigm shift in higher education (Ajonbadi, Olawoyin, & Adekoya, 2023). The digital divide is a multifaceted phenomenon that encompasses various dimensions, including socioeconomic status, geographic location, age and gender (Vartanova & Gladkova, 2019). The digital divide is not just about physical access to technology but also encompasses the skills and motivation required to effectively utilize these technologies. This was further reinforced by (Scheerder, van Deursen, & van Dijk, 2019), who highlight the importance of digital literacy and the ability to critically evaluate and create digital content. A key factor contributing to the digital divide is the uneven distribution of internet infrastructure and broadband connectivity, particularly in rural and remote areas. This disparity not only limits access to educational and economic opportunities but also heightens existing social inequalities Consequently, bridging this gap has become a priority for policymakers and stakeholders worldwide (Jamil, 2021).

However, the digital divide is not limited to access to ICT devices or the internet but also includes unevenness in the ability to effectively use the technologies, including divides in terms of access or no access to information, ICT devices, or the internet. A review of the digital divide by (Lythreatis, Singh, & El-Kassar, 2022), identified factors affecting the digital divide, including sociodemographic, socioeconomic, personal elements, and social support. It further highlighted the need for future research to address these factors to bridge the digital divide. Also, it emphasized the need for research to extend established models of digital inequalities, critically examine the effects of digital divide interventions, and better link digital divide research with research on sustainability.

Digital technologies improve efficiency through the reduction of physical resources. The adoption of e-learning platforms, digital textbooks, and online course materials has led to a substantial decrease in paper consumption and printing costs (Kapuka, Shumba, & Munthali, 2017). Also, efficiency in educational settings can be achieved by reducing the reliance on physical materials. Traditional education methods often involve significant use of ink, and physical textbooks. The shift to digital platforms, such as e-books and online course materials, has considerably decreased the need for these physical resources (Molaudzi, 2020). Moreover, digital submission and grading systems further enhance resource efficiency. These tools such as Google Classroom allow learners to submit assignments electronically, which teachers can then grade and provide feedback on digitally. This process streamlines administrative tasks, allowing educators to allocate more time to instructional activities.

Integration of educational technology in various learning environments.

The integration of educational technology into various learning environments is important for sustainable education in the evolving digital age. As technology continues to advance, educators and institutions must adapt to leverage these advancements effectively to aid teaching and learning outcomes. This study explores how digital advancements are leveraged in traditional classrooms, online learning, blended learning, STEM learning Environments.

Traditional Classroom Environment

Traditional classroom environment typically it refers to a physical place where a teacher delivers instruction to a group of learners, primarily through lectures, discussions, and assignments. Learners can gain interactivity, motivation, accessibility and organization. This enables direct communication between teacher and learners and as a result, learners are able to grow their work activity and directly clearing doubts of a particular subject in timely manner. While this model has been effective, the advancements in technology have necessitated its evolution. While the setting remains a cornerstone of learning, the integration of educational technology has emerged as an important factor in enhancing teaching and learning processes (Nicolaou, Matsiola, & Kalliris, 2019). Moreover, the integration of technology in traditional classrooms is primarily driven by the need to enhance learning outcomes and prepare learners for a technology-driven world. As (Webb & Doman, 2019) suggested, when technology is aligned with educational goals, it can significantly improve student learning outcomes. Hence, digital educational tools allow for a more personalized learning experience, catering to diverse learning styles and paces, which traditional methods may not fully address. With educational technology learners experience is more interactive and engaging. Tools such as multimedia presentations, simulations, and online resources provide learners with varied ways to access and process information (Faiz, 2021). For instance, the use of smartboards allows teachers to present dynamic content and facilitates interactive lessons, which can improve student engagement and understanding. Additionally, digital tools such as learning management systems (LMS) like Moodle enable teachers to manage course materials, track student progress, and communicate with learners more efficiently (Deliwe, 2020).

Online learning

Online learning environments have transformed education, offering a range of benefits that cater to diverse learning needs and preferences. These environments, often facilitated through Virtual Learning Environments (VLEs) or Learning Management Systems (LMS), providing learners and educators with flexible, accessible, and interactive platforms for teaching and learning (Maliki, Kusuma, Tabrani, & Hamidah, 2021). These Learning environments could promote inclusivity by allowing learners who may feel anxious in traditional classroom settings to participate more freely. This is particularly beneficial learners who might struggle with in-person interactions. Additionally, VLEs are accessible to anyone with a stable internet connection and a computer, enabling learners with mobility challenges to engage in education without physical barriers (Nwabude, Ogwueleka, & Irhebhude, 2020). Online learning environments offers flexibility, where learners can learn at their own pace, accessing course materials and lectures at times that suit them best. This self-directed approach allows for better time management and accommodates individual learning styles (Rosar & Weidlich, 2022). The study further stated that

creative learners reported more motivation after learning in an unstructured online learning environment, whereas non-creative learners reported relatively better learning experiences in the highly structured condition. Also, virtual online learning enables learners connect with others from different backgrounds, giving a sense of collaboration. This interaction not only enhances teamwork skills but also broadens learners' perspectives by exposing them to different ideas (Herrera-Pavo, 2021). Hence, integrating educational technologies into the online classroom can enhance a student-centered environment that supports learners' needs. (Samoylenko, Zharko, & Glotova, 2022) emphasizes the importance of designing flexible and reliable online learning environments that require both technical skills (digital literacy fundamentals) and methodological assistance. Therefore, learners and teachers must have access to appropriate devices and a reliable internet connection to effectively participate in online learning.

Blended learning

Blended learning, as defined by (Garrison & Norman, 2007), is a pedagogical approach that combines face-to-face and online learning to improve the overall learning experience. It involves a purposeful selection of activities and resources to address student needs, interests, and learning styles. It as a model that merges traditional classroom instruction with online learning activities, allowing for a more personalized and adaptable educational experience. This integration is particularly relevant in the context of sustainable education, as it enables the incorporation of sustainability principles into the curriculum (Dakhi, Jama, Irfan, Ambiyar, & Ishak., 2020). The study concluded that, the strength of the blended learning model is that it can increase interaction between learners anytime and anywhere, as rapidly growing technology integration has brought powerful changes to the educational system and improved digital skills for learners and lecturers. The integration of educational technology into blended learning is grounded in constructivist learning theories (Vygotsky, 1978), which emphasize the active construction of knowledge through interaction with the environment. Also, (Kumar, et al., 2021), stated that blended learning combines face-to-face instruction with online learning, enabling personalized and learner-centered experiences. In the integration of educational technology in blended learning, different technological tools have been employed. Learning management systems (LMS) (Al-Hunaiyyan, Al-Sharhan, & AlHajri, 2020) have become ubiquitous, providing platforms for content delivery, assessment, and communication. Furthermore, the proliferation of mobile devices has enabled ubiquitous learning, offering opportunities for anytime, anywhere access to educational resources (Criollo-C, Guerrero-Arias, Jaramillo-Alcázar, & Luján-Mora, 2021).

STEM learning

STEM (Science, Technology, Engineering, and Mathematics) learning environments are spaces where learners engage in active, contextualized, and meaningful learning experiences through participation, collaborative work, problem-solving, integration of disciplines, creativity, and autonomy. These learning environments aim to develop 21st-century competencies and skills for life. The STEM learning environments involve the integration of two or more STEM disciplines to solve problems and importantly, learners using their knowledge and skills from various fields to tackle real-world challenges (Dare, Keratithamkul, Hiwatig, & Li, 2021); the study showed that

all teacher who participated in the study viewed STEM education from an integrative perspective that promotes the development of 21st century skills, using real-world problems to motivate learners. The findings also revealed that teachers have varying ideas related to the STEM disciplines within integrated STEM instruction, which could assist teacher in preparing high-quality professional development experiences. Also, at the core of STEM education is inquiry-based learning, where learners actively construct knowledge through exploration and experimentation. This approach encourages learners to ask questions, formulate hypotheses, and seek answers through investigation. In the study of (Amin, Rahmawati, Sudrajat, & Mardiah, 2022), on enhancing primary school learners' critical thinking by implementing an interdisciplinary STEM approach, it was observed that learners were experiencing the enhancement of critical thinking skills through information exploration and project discussion to engage them in identifying questions at issues raised in learning. Also, facilitating learners to integrate their thought into real-life and project-making leads them to improve their conceptual understanding. Furthermore, educational technology offers a lot of tools and resources that can transform STEM learning. Simulations, virtual laboratories, and interactive software provide learners with hands-on experiences that complement traditional classroom instruction (Hernández-de-Menéndez, Guevara, & Morales-Menendez, 2019). Moreover, these technologies can facilitate problem-solving, and critical thinking, which are key competencies for STEM success (Mishra & Koehler, 2006). For implementation, researchers like (Dikmen & Demirer, 2022) emphasize the importance of Technological Pedagogical Content Knowledge (TPACK) for effective technology integration. This means that teachers need to possess a deep understanding of both technology and pedagogy to leverage technology effectively in their classrooms.

While the potential benefits of technology integration in education are substantial, there are also challenges to overcome. These include issues such as teacher training, lack of adequate infrastructure, and concerns about student screen time. To address these challenges, policymakers, educators, and technology developers need to collaborate to create supportive learning environments. However, despite these challenges, the opportunities for technology-enhanced education are unlimited, as emerging technologies such as augmented reality, virtual reality, and artificial intelligence offer new possibilities for engaging and immersive learning experiences.

Challenges and opportunities associated with the adoption of digital technologies in education

The adoption of digital technologies in education is the integration of digital tools and platforms into teaching and learning processes (Valverde-Berrocoso, Ferna´ndez-Sa´nchez, Dominguez, & Sosa-Dı´az, 2021). This shift has been driven by the necessity to enhance learning outcomes, improve accessibility, and prepare learners for a digital future. This process involves a shift from traditional methods to more technologically-driven approaches to enhance student learning outcomes and achievement, teaching methodologies, and overall educational efficiency. This process encompasses acquisition, implementation, and sustained use of digital technologies within educational institutions. The initial phase of adoption involves procuring necessary hardware, software, and digital resources (Alenezi, 2023). This includes devices such as computers, tablets,

and interactive whiteboards, as well as educational software, learning management systems (LMS), and online content platforms. Further, is the implementation of the technology, which focuses on integrating digital technologies into the curriculum, pedagogical issues, and assessment practices. This will involve teacher training, curriculum development, and the creation of digital learning materials. On sustainability, the long-term adoption of digital technologies will require ongoing support, maintenance, and professional development. It involves ensuring that technology is used effectively in teaching, learning and consistently over time, and adapting to emerging technological advancements (Gros & García-Peñalvo, 2023).

Factors Influencing Adoption

Several factors influence the adoption of digital technologies in education:

- Teacher readiness: Teachers' technological literacy, pedagogical knowledge, and willingness to embrace change are important for successful technology adoption. (Raygan & Moradkhani, 2020), (Akar, 2019), (Mardiana, 2020).
- Infrastructure: Adequate internet connectivity, computer labs, and technical support are essential for effective technology integration. (Agormedah, Henaku, Ayite, & Ansah, 2020), (Dong, Xu, Chai, & Zhai, 2019).
- Curriculum alignment: The curriculum should be aligned with the use of digital technologies to maximize their impact on student learning. (Qureshi, Khan, Raza, Imran, & Ismail, 2021), (Liu, Geertshuis, & Grainger, 2020)
- Leadership support: Strong leadership and administrative support are vital for creating a conducive environment for technology adoption. (Clohessy, Acton, & Rogers, 2018), (Karakose, Polat, & Papadakis, 2021).
- Digital divide: Access to technology and digital literacy vary among learners, which can impact the effectiveness of technology integration. (Youssef, Dahmani, & Ragni, 2022), (van de Werfhorst, Kessenich, & Geven, 2022).

Challenges

1. Infrastructure and Access: One primary challenge is the lack of adequate infrastructure, particularly in developing countries like Nigeria. Many educational institutions struggle with limited access to reliable internet and digital devices, which hinders effective technology integration (Ndibalema, 2022).
2. Teacher Training and Support: Effective adoption requires that teachers are adequately trained to use digital tools. Studies indicate that many educators feel unprepared to integrate technology into their teaching practices, leading to inconsistent application and underutilization of available resources (Opeyemi, et al., 2019), (Bui, 2022).
3. Resistance to Change: Some educators and institutions resist adopting new technologies due to fear of change or a lack of understanding of the benefits. This resistance can slow

down the integration process and limit the potential advantages of digital tools (Konaklı & Akdeniz, 2022), (Masry-Herzalah & Dor-Haim, 2022).

Discussion

The impact of digital technologies on educational sustainability is complex and multifaceted. While they offer significant benefits in terms of accessibility and efficiency, they also present challenges that must be addressed to ensure truly sustainable educational practices. The potential for digital technologies to democratize education and break down barriers to learning is immense. Online platforms and resources can reach learners in remote or underserved areas, providing access to high-quality educational content that was previously unavailable. This increased accessibility aligns well with sustainability goals, as it promotes equitable access to education. However, the digital divide remains a significant obstacle to realizing this potential fully. The uneven distribution of digital access and skills can exacerbate existing inequalities, undermining the sustainability of educational practices. Addressing this divide requires a multifaceted approach, including improving infrastructure, enhancing digital literacy, and ensuring equitable access to devices and the internet. From an efficiency standpoint, digital technologies offer clear benefits. The reduction in physical resource consumption, such as paper and textbooks, aligns with sustainability goals by decreasing waste and conserving resources. Additionally, the streamlining of administrative tasks through digital tools can potentially lead to more effective use of educators' time and resources. The environmental impact of digital technologies in education is more nuanced. While they reduce the need for physical resources, the energy consumption of data centers and the problem of electronic waste present new sustainability challenges. To fully realize the sustainability potential of digital technologies in education, these issues must be addressed through strategies such as improving energy efficiency, transitioning to renewable energy sources, and implementing effective e-waste management practices.

Further, integration of educational technology across various learning environments represents a significant shift in educational practices, aiming to enhance learning outcomes and prepare students for a technology-driven world. This integration aligns with the principles of sustainable education by promoting accessibility, efficiency, and adaptability in learning. In traditional classroom settings, technology integration has transformed the learning experience from a teacher-centered to a more student-centered approach. The use of digital tools and LMS not only enhances engagement but also allows for more personalized learning experiences. This shift addresses diverse learning styles and paces, potentially leading to improved learning outcomes. Online learning environments have revolutionized access to education, breaking down geographical and physical barriers. The flexibility and accessibility offered by VLEs promote inclusivity, allowing learners with various needs and circumstances to participate in education. However, the success of online learning heavily depends on digital literacy and access to technology, highlighting the ongoing challenge of the digital divide. Blended learning emerges as a balanced approach, combining the benefits of face-to-face instruction with online learning. This model allows for the integration of sustainability principles into the curriculum while providing a flexible and

personalized learning experience. The success of blended learning relies on the effective use of technology and the adaptation of pedagogical approaches to leverage both online and in-person components. In STEM learning environments, technology integration plays a important role in developing 21st-century skills. The use of simulations, virtual laboratories, and interactive software provides hands-on experiences that might be otherwise difficult or expensive to implement. This approach not only enhances understanding of complex concepts but also promotes problem-solving and critical thinking skills essential for STEM fields. While the benefits of technology integration in education are significant, challenges remain. These include the need for adequate teacher training, infrastructure development, and addressing concerns about excessive screen time. The concept of Technological Pedagogical Content Knowledge (TPACK) emphasizes the importance of teachers understanding both technology and pedagogy to effectively implement these tools.

One of the primary challenges highlighted is the issue of infrastructure and access. This is particularly pronounced in developing countries, where reliable internet connectivity and access to digital devices may be limited. This challenge underscores the global digital divide and raises concerns about educational equity. As education becomes increasingly reliant on digital technologies, there's a risk of widening the gap between those with access to these resources and those without, potentially exacerbating existing educational disparities.

References

Adeniyi, S., Al Hamad, N., Adewusi, O., Unachukwu, C., Osawaru, B., Onyebuchi, C., . . . David, I. (2024). E-learning platforms in higher education: A comparative review of the USA and Africa. *International Journal of Science and Research Archive, 11*(1), 1686–1697.

Agormedah, E. K., Henaku, E. A., Ayite, D. M., & Ansah, E. A. (2020). Online Learning in Higher Education during COVID-19 Pandemic: A case of Ghana. *Journal of Educational Technology & Online Learning, 3*(3), 183-210.

Ajonbadi, H., Olawoyin, F., & Adekoya, O. (2023). The Anathema of Digital Divide in the Nigerian Higher Education: Lessons from the Pandemic. *Beyond the Pandemic Pedagogy of Managerialism*, 189–208.

Akar, S. (2019). Does it matter being innovative: Teachers' technology acceptance. *Education and Information Technologies, 24*, 3415–3432.

Alam, A., & Mohanty, A. (2023). Educational technology: Exploring the convergence of technology and pedagogy through mobility, interactivity, AI, and learning tools. *Cogent Engineering, 10*(2).

Alenezi, M. (2023). Digital Learning and Digital Institution in Higher Education. *Education Sciences, 33*(18), 1-18.

Al-Hunaiyyan, A., Al-Sharhan, S., & AlHajri, R. (2020). Prospects and Challenges of Learning Management Systems in Higher Education. *International Journal of Advanced Computer Science and Applications, 11*(12), 73-79.

Aljawarneh, S. (2020). Reviewing and exploring innovative ubiquitous learning tools in higher education. *Journal of Computing in Higher Education, 32*, 57–73.

Almohammadi, K., Hagras, H., Alghazzawi, D., & Aldabbagh, G. (2017). A Survey Of Artificial Intelligence Techniques Employed For Adaptive Educational Systems Within E-Learning Platforms. *JAISCR, 7*(1), 47-64.

Amin, M., Rahmawati, Y., Sudrajat, A., & Mardiah, A. (2022). Enhancing Primary School Students' Critical Thinking Skills through the Integration of Inquiry-Based STEM Approach on Teaching Electricity in Science Learning. *Journal of Physics: Conference Series*, 1-6.

Anub, A., Vaza, R., Parmar, A., Mishra, P., Abdullah, I., & Velu, C. (2024). Security And Privacy Concerns In AI-Enabled Iot Educational Frameworks: An In-Depth Analysis. *Educational Administration: Theory and Practice, 30*(4), 8436–8445.

Azubuike, O., Adegboye, O., & Quadri, H. (2012). Who gets to learn in a pandemic? Exploring the digital divide in remote . *International Journal of Educational Research Open learning during the COVID-19 pandemic in Nigeria*, 1-10.

Blazic, B., & Blazic, A. (2020). Overcoming the digital divide with a modern approach to learning digital skills for the elderly adults. *Educ Inf Technol, 25*, 259–279.

Bordoloi, R., Das, P., & Das, K. (2021). Perception towards online/blended learning at the time of Covid-19 pandemic: an academic analytics in the Indian context. *Asian Association of Open, 16*(1), 41-60.

Bui, T. (2022). English teachers' integration of digital technologies in the classroom. *International Journal of Educational Research Open, 3*, 1-15.

Calderón, D. (2018). The Three Levels of the Digital Divide: Barriers in Access, Use and Utility of Internet among Young People in Spain. *Sociedade e as novas modernidades, 34*, 64 – 91.

Cebrián, G., Palau, R., & Mogas, J. (2020). The Smart Classroom as a Means to the Development of ESD Methodologies. *Sustainability, 12*(7), 1-18.

Chankseliani, M., & McCowan, T. (2020). Higher education and the Sustainable Development Goals. *Higher Education , 81*, 1–8.

Clohessy, T., Acton, T., & Rogers, N. (2018). Blockchain Adoption: Technological, Organisational and Environmental Considerations. *Business Transformation through Blockchain*, 47–76.

Criollo-C, S., Guerrero-Arias, A., Jaramillo-Alcázar, Á., & Luján-Mora, S. (2021). Mobile Learning Technologies for Education: Benefits and Issues. *Applied Sciences, 11*(9), 1-17.

Dakhi, O., Jama, J., Irfan, D., Ambiyar, A., & Ishak. (2020). Blended Learning: A 21th Century Learning Model at College. *International Journal for Multiscience, 7*, 50-64.

Dare, E., Keratithamkul, K., Hiwatig, B., & Li, F. (2021). Beyond Content: The Role of STEM Disciplines, Real-World Problems, 21st Century Skills, and STEM Careers within Science Teachers' Conceptions of Integrated STEM Education. *Education Sciences, 11*(737), 1-22.

Deliwe, A. (2020). The Use of Learner Management System (MOODLE) in Promoting Teaching and Learning. *Universal Journal of Educational Research, 8*(12B), 8383-8392.

Dikmen, C., & Demirer, V. (2022). The role of technological pedagogical content knowledge and social cognitive variables in teachers' technology integration behaviors. *Participatory Educational Research, 9*(2), 398 - 415.

Dong, Y., Xu, C., Chai, C., & Zhai, X. (2019). Exploring the Structural Relationship Among Teachers' Technostress, Technological Pedagogical Content Knowledge (TPACK), Computer Self-efficacy and School Support. *The Asia-Pacific Education Researcher, 29*, 147–157.

Faiz, T. (2021). The use of educational technology for interactive teaching in lectures. *Annals of Medicine & Surgery, 62*, 231-235.

Falloon, G. (2020). From digital literacy to digital competence: the teacher digital competency (TDC) framework. *Education Tech Research Dev, 68*, 2449–2472.

Fang, M., Canham, S., Battersby, L., Sixsmith, J., Wada, M., & Sixsmith, A. (2019). Exploring Privilege in the Digital Divide: Implications for Theory, Policy, and Practice. *The Gerontologist, 59*(1), 1-15.

Faturoti, B. (2022). Online learning during COVID19 and beyond: a human right based approach to internet access in Africa. *International Review of Law, Computers & Technology, 36*(1), 68–90.

Garrison, D., & Norman, D. (2007). *Blended Learning in Higher Education: Framework, Principles, and Guidelines.* Jossey-Bass.

Grimus, M. (2020). Emerging Technologies: Impacting Learning, Pedagogy and Curriculum Development. In S. Yu, A. M., & A. Tsinakos, *Emerging Technologies and Pedagogies in the Curriculum. Bridging Human and Machine: Future Education with Intelligence* (pp. 127–151). Singapore: Springer.

Gros, B., & García-Peñalvo, F. (2023). Future Trends in the Design Strategies and Technological Affordances of E-learning. In J. Spector, B. Lockee, & M. Childress, *Learning, Design, and Technology* (pp. 345–367). Switzerland : Springer, Cham.

Hernández-de-Menéndez, M., Guevara, A., & Morales-Menendez, R. (2019). Virtual reality laboratories: A review of experiences. *International Journal on Interactive Design and Manufacturing (IJIDeM), 13*, 947–966.

Herrera-Pavo, M. (2021). Collaborative learning for virtual higher education. *Learning, Culture and Social Interaction, 28*(100437), 1-11.

Hogan, D., & O'Flaherty, J. (2022). Exploring the nature and culture of science as an academic discipline: implications for the integration of education for sustainable development. *International Journal of Sustainability in Higher Education, 23*(8), 120-147.

Jamil, S. (2021). From digital divide to digital inclusion: Challenges for wide-ranging digitalization in Pakistan. *Telecommunications Policy, 45*(8), 1-10.

Kapuka, M., Shumba, O., & Munthali, W. (2017). Students' attitudes to paper consumption in relation to carbon emissions and the impact of electronic course documents. *Southern African Journal of Environmental Education, 33*(1), 84-98.

Karakose, T., Polat, H., & Papadakis, S. (2021). Examining Teachers' Perspectives on School Principals' Digital Leadership Roles and Technology Capabilities during the COVID-19 Pandemic. *Sustainabilit, 13*, 1-20.

Konaklı, T., & Akdeniz, R. (2022). The Emergence, Reasons and Results of Resistance to Change in Teachers. *International Journal on Lifelong Education and Leadership, 8*(1), 1-19.

Kumar, A., Krishnamurthi, R., Bhatia, S., Kaushik, K., Ahuja, N., Nayyar, A., & Masud, M. (2021). Blended Learning Tools and Practices: A Comprehensive Analysis. *IEEE, 9*, 85151-85197.

Lake, J. (2022). Using Cloud-based Collaborative Office Productivity Tools (Google Workspace) to Engage Students in Their Learning and Prepare Them for the Workplace. In E. Sengupta, & P. Blessinger, *ICT and Innovation in Teaching Learning Methods in Higher Education (Innovations in Higher Education Teaching and Learning* (Vol. 45, pp. 161-179). Leeds: Emerald Publishing Limited.

Liu, Q., Geertshuis, S., & Grainger, R. (2020). Understanding academics' adoption of learning technologies: A systematic review. *Computers & Education, 151*, 1-19.

Lythreatis, S., Singh, S. K., & El-Kassar, A.-N. (2022). The digital divide: A review and future research agenda. *Management of Technology and Innovation*.

Maliki, B. I., Kusuma, J. W., Tabrani, M. B., & Hamidah, H. (2021). Identification Of Education In Indonesia And Learning Models In Student Learning With Learning Management System (LMS). *International Journal of Economy, Education and Entrepreneurship, 1*(1), 37–46.

Mardiana, H. (2020). Lecturers' Adaptability To Technological Change And Its Impact On The Teaching Process. *JPI, 9*(2), 275-289.

Martens, M., Hajibayova, L., Campana, K., Rinnert, G., Caniglia, J., Bakori, I., . . . Oh, O. (2020). Being on the wrong side of the digital divide": seeking technological interventions for education in Northeast Nigeria. *Aslib Journal of Information Management, 72*(6), 963-978.

Masry-Herzalah, A., & Dor-Haim, P. (2022). Teachers' technological competence and success in online teaching during the COVID-19 crisis: the moderating role of resistance to change. *International Journal of Educational Management, 36*(1), 1-13.

Molaudzi, A. (2020). The Role of Resources in Promoting Teaching and Learning in South Africa. In K. Adeyemo, *The Education Systems of Africa. Global Education Systems* (pp. 1-20). Springer Nature: Springer, Cham.

Navarrete, R., & Luján-Mora, S. (2018). Bridging the accessibility gap in Open Educational Resources. *Universal Access in the Information Society, 17*, 755–774.

Ndibalema, P. (2022). Constraints of transition to online distance learning in Higher Education Institutions during COVID-19 in developing countries: A systematic review. *E-Learning and Digital Media, 19*(6), 595-618.

Nicolaou, C., Matsiola, M., & Kalliris, G. (2019). Technology-Enhanced Learning and Teaching Methodologies through Audiovisual Media. *Education Sciences, 9*(196), 1-13.

Nwabude, A., Ogwueleka, F., & Irhebhude, M. (2020). The Use of Virtual Learning Environment and the Development of a Customised Framework/Model for Teaching and Learning Process in Developing Countries. *Education, 10*(1), 1-12.

Ogbo, E., Brown, T., Gant, J., & Sicker, D. (2021). When Being Connected is not Enough: An Analysis of the Second and Third Levels of the Digital Divide in a Developing Country. *Journal of Information Policy, 11*, 104–146.

Olanrewaju, B., & Afolabi, J. (2022). Digitising education in Nigeria: lessons from COVID-19. *International Journal of Technology Enhanced Learning, 14*(4), 402-419.

Oluwagbemileke, F. (2024). NARRATIVE REVIEW OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) INTEGRATION IN NIGERIAN SECONDARY SCHOOLS' HOME ECONOMICS INSTRUCTION. *Nigeria Journal of Home Economics, 12*(10), 144-151.

Onesi-Ozigagun, O., Ololade, Y., Eyo-Udo, L., & Ogundipe, D. (2024). Revolutionalizing Education through AI: A Comprehensive Review of enhancing Learning Experiences. *International Journal of Applied Research in Social Sciences, 6*(4), 589-607.

Opeyemi, D., Ayodele, V., Alufa, O., Anderson, E., Strachan, R., & Emembolu, I. (2019). Barriers and Identified Solutions to the Integration of Digital Technologies in the Classroom: A Case Study of Teachers in Nigeria. *2019 IEEE Global Engineering Education Conference (EDUCON)* (pp. 953-958). Dubai, United Arab Emirates: IEEE .

Qureshi, M. I., Khan, N., Raza, H., Imran, A., & Ismail, F. (2021). Digital Technologies in Education 4.0. Does it Enhance Effectiveness of Learning? A Systematic Literature Review. *iJIM, 15*(4), 31–47.

Raygan, A., & Moradkhani, S. (2020). Factors influencing technology integration in an EFL context: investigating EFL teachers' attitudes, TPACK level, and educational climate. *Computer Assisted Language Learning, 35*(8), 1789–1810.

Rosar, M., & Weidlich, J. (2022). Creative students in self-paced online learning environments: an experimental exploration of the interaction of visual design and creativity. *Research and Practice in Technology Enhanced Learning, 17*(8), 1-24.

Samoylenko, N., Zharko, L., & Glotova, A. (2022). Designing Online Learning Environment: ICT Tools and Teaching Strategies. *Athens Journal of Education, 9*(1), 49-62.

Scheerder, A., van Deursen, J., & van Dijk, A. (2019). Negative outcomes of Internet use: A qualitative analysis in the homes of families with different educational backgrounds. *The Information Society*, 286-298.

Shava, E. (2022). Reinforcing the Role of ICT in Enhancing Teaching and Learning Post-COVID-19 in Tertiary Institutions in South Africa. *Journal of Cultural Education and Values, 5*(1), 78-91.

Spiteri, M., & Chang-Rundgren, S. (2020). Literature Review on the Factors Affecting Primary Teachers' Use of Digital Technology. *Tech Know Learn, 25*, 115–128.

Straková, Z., & a Cimermanová, I. (2018). Critical Thinking Development—A Necessary Step in Higher Education Transformation towards Sustainability. *Sustainability, 10*, 1-18.

Suresh, K., & Srinivasan, P. (2020). Massive Open Online Courses – Anyone Can Access Anywhere at Anytime. *Shanlax International Journal of Education, 8*(3), 96–101.

Takyi, S. A., Amponsah, O., Asibey, M. O., & Ayambire, R. A. (2019). An overview of Ghana's educational system and its implication for educational equity. *International Journal of Leadership in Education, 24*(2), 157–182.

UNESCO. (2017). *Education for Sustainable Development Goals Learning Objectives.* France: United Nations Educational, Scientific and Cultural .

Valverde-Berrocoso, J., Ferna´ndez-Sa´nchez, M., Dominguez, F., & Sosa-Dı´az, M. (2021). The educational integration of digital technologies preCovid-19: Lessons for teacher education. *PLoS ONE, 16*(8), 1-22.

van de Werfhorst, H., Kessenich, E., & Geven, S. (2022). The digital divide in online education: Inequality in digital readiness of students and schools. *Computers and Education Open, 3*, `1-15.

Vartanova, E., & Gladkova, A. (2019). New forms of the digital divide. *Digital media inequalities: Policies against divides, distrust and discrimination*, 193-213.

Vygotsky, L. S. (1978). *Mind in society: Development of higher psychological processes.* Cambridge : Harvard University Press.

Webb, M., & Doman, E. (2019). Impacts of flipped classrooms on learner attitudes towards technology-enhanced language learning. *Computer Assisted Language Learning, 33*(3), 240-274.

Youssef, A., Dahmani, M., & Ragni, L. (2022). ICT Use, Digital Skills and Students' Academic Performance: Exploring the Digital Divide. *Information, 13*(129), 1-19.