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Sustainable Learning Ecosystem: New Digital Media Technology Approach for Nigeria

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ABSTRACT
The rapid advancement of digital technology has become a global priority for sustainable education by creating new tools and methods that facilitate innovative teaching and research. Despite the benefits, Nigerian educational system is bedeviled by contemporary challenges such as scarce resources, infrastructural decay, digital divide and unequal access to quality education. The extant multi-disciplinary literature drawn from key articles published between 2016 and 2025. The study examines the theories, methodologies and perspectives that leverage modern technological tools for inclusive and resource-efficient education, as aligned to SDGs 4 and 13. The thematic analysis utilized secondary sources and discussed basic SLE components, post COVID-19 challenges and opportunities for green transformation. The study proposed a comprehensive framework for developing learning ecosystems that support learners' independence, collaboration, and flexibility, derived from research. The study further recommends policy reforms, infrastructural investments and teacher training for building sustainable and conducive learning ecosystem that will stand the test of time in Nigeria.

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INTRODUCTION

The rapid technological advancement remained the major mechanism characteristic of the 21st century, especially in providing a critical paradigm shift to educational reforms for sustainable learning ecosystem. Sustainable learning ecosystem refers to the integrated model in which education promotes environmental friendliness, resource efficiency, and continuous learning by leveraging digital technologies as success tools (Nwafor-Orizu & Okonkwo, 2024; Radenkova, 2024).

Nigerian educational ecosystem is characterised by infrastructural disparities, over-reliance on printed materials in schools, climate vulnerabilities that led to having over ten million school dropouts, where adoption of new digital media technology could guarantee green transformation (Abubakar & Ekele, 2025). The digital technology tools comprise of e-learning platforms, internet of things (IoT), artificial intelligence (AI), mobile application, virtual reality (VR), audiovisual generation tools, cloud-based systems and information and communication technology based pedagogies that enhance accessibility, reduce physical resource reliance and facilitate green practices (Alam & Mohanty, 2023; Ambe et al., 2024). With these golden opportunities, access to quality education can be harnessed from remote areas as corroborated by the sustainable development goals (SDGs) 4 and 13 for quality education and climate action respectively.

Despite the Nigeria's several attempts to advance its educational ecosystem, the traditional teacher-centered method of knowledge delivery remained dominant, failing to harness the 21st century technological potential skills that aid creativity, critical thinking, and digital literacy for competition at global pace (Chukwuemeka et al., 2025; Oguntoye, 2024). This inflexibility is not unconnected to the challenges of inadequate

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infrastructure, lack of teacher training, limited digital technology resources and heavy reliance on paper-based processes, which led to environmental wastes and hindrance of sustainable development (Agbeyangi et al., 2024)

The COVID-19 pandemic exposed the potentials of new digital media technologies for inclusive, flexible learning and yet its adoption remained unattainable due to challenges, such as unstable and inadequate power supply, low digital literacy, and imbalance of access to quality education (Ajamu et al., 2023). However, the integration of the new digital media technology for quality education is undermined by the contextual resource constraints and a disconnection between the theoretical principles and practice (Onyejelem, 2025). These gaps highlight the need for sustainable learning environment in Nigeria to leverage the advantages of the new media technology that could bridge between digital divide and educational needs for global sustainability agenda.

The paper syntheses literature from international to local perspectives to propose right approach to digital media technology for building sustainable learning ecosystem in Nigeria. It drew concepts such as; Promoting a digital learning ecosystem in Nigeria (Achebo, 2022), emerging smart green schools (Nwafor-Orizu & Okonkwo, 2024), building a sustainable model for Distance Learning (Hilary et al., 2025), e-learning and sustainability in higher education in sub-saharan Africa (Omanyo & Ndiege, 2024), academic social media knowledge sharing model among academicians in higher education institutions in Nigeria (Geidam & Dahlan), e-learning for open and distance learning (Nkemdilim et al., 2024), innovative technology strategies in primary education (Abubakar & Ekele, 2025), audiovisual science communication (Onyejelem, 2025), electronic media learning technologies and environmental education pedagogy (Ambe et al., 2024) and E-waste management practices through the eyes of responsible departments (Hashim et al., 2025). By integrating these literature, the paper highlights challenges, benefits, strategies and implication for Nigeria.

Based on the forgoing, the study aimed to explore underpinning theories and practical methodologies for constructing sustainable, inclusive, and adaptive learning ecosystems that cater to different learning requirements. Specifically, the study targets to achieve the following objectives:

1. To review theories and methodologies relevant to media technologies for sustainable education in Nigeria.
2. To identify the key challenges and benefits to integrating digital technologies for sustainability in higher education in Nigeria.
3. To propose policy recommendations and frameworks for enhancing teacher training, infrastructure development, and stakeholder collaboration to support sustainable learning ecosystems.

The conceptual paper was drawn from multidisciplinary perspectives, such as systems theory, theory of constructivism and ecological learning models, that proposed a comprehensive framework for Nigerian context. The thematic analysis synthesized relevant literature on frequent themes such systems theory views education as a complex and interdependent system, which provides a foundational view for understanding how new digital media can incorporate formal, informal and non-formal modalities of learning, which mostly conducted to reflect Nigerian context. Through the examination of theoretical groundings, practical methodologies, benefits and challenges, practically guide policy-makers, technologists and educators in building ecosystem that can withstand the evolutions of technological advancements. The criteria for inclusion focused on published articles and books from 2016 to 2025, relevant to modern digital trends in guiding the framework development.

The article adopted a conceptual synthesis of relevant literature drawn from secondary sources. The thematic analysis was performed on twelve key documents, highlighting most frequent themes such as digital media, technology integration, learning ecosystem,

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sustainability practices and challenges of education, which mostly conducted to reflect Nigerian context. The criteria for inclusion focused on published articles and books from 2016 to 2025, relevant to modern digital trends in guiding the framework development. Signifies.

LITERATURE REVIEW

The section synthesized relevant literature on concepts, theories as related to the adoption of new digital media technologies to enhancement of Nigerian education.

Sustainable Learning Ecosystems

A sustainable learning ecosystem (SLE) integrates environmental, social, and economic dimensions to ensure that education continues without exhausting resources. According to Nkemdilim et al. (2024) e-learning plays a key role in a system by shifting education from the passive acquisition of knowledge to the dynamic creation of knowledge within the knowledge economy. This aligns with the Fourth Industrial Revolution, where technologies such as IoT and AI enhance learning efficiency (Nwafor-Orizu & Okonkwo, 2024). In Nigeria, implementing such ecosystems requires addressing issues like unreliable electricity and digital inequality to ensure inclusivity.

According to Qureshi et al. (2021) theoretical perspectives and conceptualization of sustainability, four key elements of SLE are identified and discussed below:

Renewing and Relearning

A fundamental principle of sustainability is the renewal of resources when needed. Furthermore, it promotes the recycle of the earth's resources to prevent depletion and extend its durability. Nevertheless, when applied to school setting, sustainable learning requires learners to revisit, update, and relearn knowledge, skills and appropriate facts when something is inappropriate. Much effort is utilised into resource sustainability assessments (Luo et al., 2025), monitoring the availability and quality of water, energy, and food, learners must periodically evaluate their own knowledge. This involves not only external indicators like grades but also self-reflection on what has been mastered and what still needs improvement for future circumstances.

Self-reflection plays a key role here, as numerous works on SLE emphasizes self-assessment (Bouzid et al., 2025). It involves recognizing what you know and identifying gaps in relation to course demands (e.g History), practical needs (how to use new appliance), or personal interests (e.g I want to learn about bulls). This process enables them to acquire new knowledge or refresh forgotten skills, particularly when technological or professional changes occur - for example, relearning a software program in an updated form for a new workplace. This assessment of "what do I know", "what I don't know" and "how can I use this knowledge appropriately" These reflective practices fall under meta-processes, which include the knowledge acquired and how it relates to cognitive, behavioral, and affective strategies (Yordanova, 2007).

Self-assessment can also be influenced by evaluation from others. For instance, a supervisor may give feedback on a specific topic or performance. Sustainable assessment is regarded as an essential component of life-long learning (Javaid et al., 2020). Individuals need to be open to external assessment to both familiar and unfamiliar learning tasks they encounter throughout life. such assessments may come from parents, teachers, peers or colleagues, supervisors, or even strangers (especially in today's online platforms). They serve as benchmarks against which learners can identify what must be updated or relearned to keep pace with evolving demands. However, this process may cause frustration, especially among younger learners who lack sufficient knowledge and experience in learning (Seale et al., 2021). While older learners generally understand how learning operates, younger ones may wrongly believe they are fully prepared to handle future tasks, even if the context or timing has changed. In this regard, educators play a vital role in helping children and youth recognize and accept that new learning and relearning are integral to SLE (Seale et al., 2021; Yordanova, 2007).

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Independent and Collaborative Learning

For learning to be sustainable, individuals must be able to study on their own while also drawing on the support of their community when necessary (Sgorla et al., 2025). However, a truly self-sustained learner develops the ability to learn independently, making use of offline and online resources, experiences, or trial and error. Sustainable Learning Ecosystems (SLE) emphasize not only the capacity for independent study but also the willingness to seek social support and scaffolding when required, balancing autonomy with collaboration. In this regard, it is important to consider the relational traits of learning such as peers, teachers, or parents either through face-to-face or online interactions (Seale et al., 2021; Sgorla et al., 2025). Independent learning involves self-directed learning, where one identifies what needs to be learned and locates relevant resources.

However, help-seeking occurs when a learner approaches someone more knowledgeable for assistance, while collaborative learning takes place in groups, with members working together on the same or related topics. Collaborative learning often includes individuals with varying levels of expertise, but unlike help-seeking, responsibility for completing the task is shared more equally (Sgorla et al., 2025; Yordanova, 2007). This could involve classmates preparing for an exam, completing group projects, or team-based tasks in the workplace. Scientific innovations are often advanced through collaboration, with each member contributing specialized expertise.

Active Learning with a Future Orientation

For learning to be maintained, learners must actively participate in their own process of learning. Active learning means that learners intentionally seek information and actively engage in the process. They monitor their progress by applying feedback loops to help them identify what remains to be done, and adjust some strategies to stay effective. While feedback loops focus on current or ongoing tasks, while a *feedforward loop* encourages learners to note improvements for future tasks. Learners may evaluate themselves or seek guidance from teachers and peers on how to improve future performance (Büyükbaykal, 2015; Hakimi et al., 2025).

This feedforward perspective underpins forward-thinking, where durable learning achieved by reusing and adapting resources within a changing global economy, while also planning ahead for uncertainties (Burke, 2021). Through feedforward loops, learners remain proactive, adjusting and maintaining strategies to fit their goals. Moreover, inactive reinforces existing habits, whereas active effort enables adaptation to evolve societal needs (Burke, 2021; Sgorla et al., 2025). Therefore, identifying what must be learned, evaluating effective strategies, and recognizing patterns are central elements of SLE that extend well beyond the classroom.

Transferability

While feedforward loops prepare learners to approach future tasks differently, transferability refers to ability to apply familiar strategies, processes, or skills across different contexts or domains (Seale et al., 2021). For instance, a learner who learns to break down a large history project into smaller steps can apply the same method when preparing for a chemistry exam. Transferability also includes using skills from one setting, such as school, in another setting, such as the workplace or home. This becomes particularly significant during transitions in life—moving from kindergarten to primary school, primary to secondary, or university to professional careers. Scholars have examined these educational or life transitions, sought to identify factors that support successful navigation (Ambe et al., 2024; Hakimi et al., 2025; Kosaretsky et al., 2022).

Underpinning Theories

The section discussed relevant theories that viewed educational resources with respect to adoption of new digital technologies aimed at improving sustainable learning ecosystem. The theories are discussed as follows:

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Connectivism Theory

Connectivism has emerged as a central theory for education in the digital era. Originally introduced by Mutiga (2023) and further refined in subsequent studies, the theory emphasizes that learning occurs through networks, with knowledge embedded in the connections among nodes such as individuals, databases, and technological devices. Within the context of sustainable education, connectivism allows learners to interlink sustainability concepts - including circular economy and Corporate Social Responsibility (CSR) through digital interactions, making it especially valuable in business and marketing programs. Dziubaniuk et al. (2023), for example, apply connectivist principles in online courses and demonstrate that digital enablers promote critical thinking around issues like greenwashing and ethical conduct, which are essential for nurturing sustainable practices.

Theories of constructivism, cognitivism and behaviourism were regarded as traditional learning environment in the late 19th century and early 20th century and applied to learning theories, while technology was ignored (Bell, 2011). However, the development of ICT provides another dimension of learning environment, called Online Society which changed the narratives of learning theory and process. connectivism theory represent a dynamic environment where individuals, groups, nodes, entities and systems are linked using a set of ICT tools such as network of computers, social networks and power grids (Karantalis & Koukopoulos, 2022; Tick & Beke, 2021). It explains process of learning where learners acquire new knowledge within a network by connecting to variety of nodes, maintaining and expanding the network connection. The Siemen's connectivism basic principle extended to learning theory are as follows: learning and knowledge lies in diversity of opinion; learning is a process of specialized nodes connection; learning may be obtained from non-human objects; the capacity to obtain more knowledge is more crucial than what was currently known; continuous learning can be facilitated by nurturing and maintaining connections; establishing and maintaining connections between ideas, fields and concepts is the critical skill; currency is the goal of all connectivism learning activities; decision making is by itself a learning process (Almalki et al., 2025; Boyraz & Ocak, 2021).

Connectivist theory is applied as an effective learning strategy to increase connection competency of learners for knowledge information in pedagogy (Boyraz & Ocak, 2021; Dziubaniuk et al., 2023; Mondal, 2025). Furthermore, all e-learning via Massive Open Online Courses (MOOCs), social media networks and internet are used as open teaching and learning materials, which produces self-directed learning outcome (Mehmood & Haroon, 2025; Sulistiyarini et al., 2025). In the past few decades, internet technology has led to the evolution of new learning tools. Thus, the roles of educational institutions and teachers in providing information and lecture delivery is paramount, as learners can enjoy from education over time and space (Hontarenko & Kovalenko, 2024). The power of the world wide web (www) in providing the avenue to perform gradual task so the internet by establishing a densely and flexible information technology for learners in the society (Alam & Mohanty, 2023; Zhao & Zhao, 2024).

Considering the benefits and shortcomings of e-learning in an environment where learning systems exist in parallel and the spread of COVID-19 led to the evolution of meta-cognitive learning models using ICT tools (Halkiopoulos & Gkintoni, 2024). The transition from classical learning to smarter methods of learning that incorporates the modern technology such as artificial intelligence (AI), YouTube channels and blockchain technology are powerful tools for students' engagement in content creation and dissemination (Bhumichai et al., 2024).

Therefore, connectivism offers a robust framework for clear understanding of how learning in the digital age is dominated by new media technology, by shifting education to networked, technology-based experiences. Harnessing the benefits of technologies such as AI, VR and Metaverse, empowers learners to handle complex and connected environments. As new technologies continue to evolve, connectivism has the potent to influence educational innovations.

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Systems Theory

Systems theory was originally developed by an Austrian biologist and a philosopher - Ludwig von Bertalanffy (1901 – 72) in the middle of 20th century as general system theory (GST), which provides inter-disciplinary framework for understanding composition of complex, but interrelated components, organized as wholes in given phenomena. GST emphasized that a system is more than the sum of its parts., featuring properties like holism, inter-dependence emergence, feedback loops and adaptation to an environment (O'Neil, 2025; Wang & Li, 2018). Within the field of education, GST emerged to view processes and educational institutions as dynamic and open system that interact with external environmental factors, such as the society, technology and policy. This approach changes the focus from isolated elements such as individual teaching methods to systemic interactions, that makes it more relevant in the digital age, where technology disrupt the traditional educational settings (Delcea et al., 2025; Wang & Li, 2018).

Systems theory provides an important complement to connectivism by viewing education as a dynamic ecosystem composed of interdependent constuents. Ellyatt (2025) explains that learning ecosystems operate as interconnected networks that ensure access to resources and promote collaboration. Within the Nigerian context, this framework implies the integration of digital platforms with community-participation to address pressing local problems, such as environmental degradation.

The basic principles of GST, as applied to the field education are: Holism - educational outcomes emanate from the interaction between different elements, (teachers, students, methods, curricula, and tools) rather than individual factors. Feedback Loops and Interdependence - Components of a system influence each other via positive and negative feedback, by way of self-regulation and adaptation. Open Systems - Educational institutions share resources and information with external environments, which can lead to evolution and potential disequilibrium. Evolution - New behaviors emerge from system interactions which are predictable from individual components alone. Hierarchy and Subsystems - Systems consist of subsystems (classrooms in schools), with clear boundaries permeable to technological contribution. Dynamic Equilibrium - Systems need balance, but susceptible innovations disruption which require adaptability and resilience (Ambe et al., 2024; Hofkirchner & Schafranek, 2011; Karantalis & Koukopoulos, 2022; Nkemdilim et al., 2024; Zhao & Zhao, 2024).

The principles motivate policy-makers and educators to adopt 'systems thinking' which refers to an approach for evaluating complexities and identifying points to leverage upon for sustainable change (Sekaringtias & Verrier, 2025). Within the context of education, this results to tools such as Causal Loop Diagrams, Social Networks Analysis and System Dynamics for mapping interactions and outcomes predictions (Oyman Bozkurt, 2025).

New digital media technologies comprise of all social media platforms, interactive platforms, AI, virtual and augmented realities, and big-data analytics aligned to system theory in transforming education into interconnected and adaptive ecosystem (Mena-Guacas et al., 2025). These technologies serve as sub-systems that provide feedbacks for global connectivity, enhancement and personalization, while posing a challenge onto the traditional boundaries and hierarchies (Halkiopoulos & Gkintoni, 2024; Mena-Guacas et al., 2025).

System theory offers robust methodology for new digital media technologies integrations in education and promoting adaptation through holistic approach that can groom learners for complex and unpredictable future. This approach will help learners for the ability to interconnect subsystems, enhance personalization and collaboration. Therefore, system theory will continue to remain relevant for sustainable educational transformation, as new digital technology tools continue to evolve.

Education for Sustainable Development (ESD) Theory

The theory of Education for Sustainable Development (ESD), drawn by United Nation's

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Education, Social and Cultural Organization (UNESCO) in 2020, stresses the need for transformative learning approaches that build competencies in sustainability. ESD considered education as transformation mechanism for addressing global challenges, such as climate change, poverty, bio-diversity and inequality by motivating learners in taking responsible actions and making informed decisions for social justice, economic security and environmental integrity (Zinchenko, 2022). In contrast to traditional education aimed in transmission of knowledge, ESD maintained sustainability as all learning levels, inter-disciplinary approach, holistic emphasis that develop skills, promote value and behavious for future sustainability (White & Preist, 2025). ESD enhances earlier concepts, such as environmental education, but extends to comprise social, cultural and economic dimension that aligns with specifically SDG4 for quality education (Chien & Knoble, 2024; White & Preist, 2025; Zinchenko, 2022).

Gomaa and Gauthier (2024) extend this discussion by connecting ESD with technological innovation, proposing the Sustainable EdTech for Sustainability (SETS) model. This framework encourages the adoption of eco-design digital tools designed to reduce environmental impact while also supporting comprehensive understandings of sustainability. New capabilities of delivering technological innovations in the EdTech sector, coupled with current environmental crises, emphasized the need for radical shift to design EdTech for integrating as well as promoting environmental and sustainable learning. Sustainability is not just a fashion, rather it is a necessity that need integration in to educational curricular for environmental awareness of future generations.

Consequently, Thomas et al. (2024) noted that integrating EdTech into curriculum and operations can be a powerful mechanism for sustainable business practices, promote environmental awareness, promote behavior sustainability and a tool for addressing climate challenges and resource drains. Similarly, Gomaa and Gauthier (2024) argued that imparting early view in EdTech might help in transforming the industry by reshaping students' and users' beliefs for practice and rethinking sustainability.

ESD theory serves as vital framework for educational innovation disruption towards sustainability, harnessing new digital media technologies that enhances transformative learning and ethical usage for global impact.

Adaptive learning Theory

Theories of adaptive learning place emphasis on personalization, often facilitated by artificial intelligence (AI), to maximize efficiency in both learning and resource use. Rincon-Flores et al. (2024) reveal how adaptive methods, when integrated with flipped classroom strategies, improve teaching effectiveness and student achievement. For developing nations, Nigeria inclusive, such innovations can also help reduce dropout rates by catering to learners with diverse needs and learning speeds.

Adaptive learning theory built upon the existing educational models such as first, Behaviourist Roots – earlier programmed instructions that emphasized on feedback-driven and sequenced learning automated by digital technologies via algorithms, which adjust difficulty based on performance (Ray, 2004). Second, Constructivist Influences – learners construct knowledge self-exploration as corroborate with Vygotsky's Zone of Proximal Development (ZPD), that adaptive system support this by just-in-time resource provisions such as multi-media illustrations coupled with cognitive gaps (El-Sabagh, 2021). Third, Cognitive and Humanistic Element – encorporated learning styles to enhance self-directed development, through the use of assessments for mapping needs and dynamically adjusting contents (Ray, 2004).

The perspective of adaptive learning extends beyond the basic theory by encompassing behaviourist and constructivist influence, where learning is viewed as interactive and active process, coordinated by personalization and instantaneous feedback (Ling et al., 2025). In the light of new digital media technology, data analytics tools, interactive multi-media and AI-powered platforms have the

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potentials for transforming education to be more interactive and learner-centered experience.

Digital Media Technologies in Education

Digital media technologies comprise tools including virtual learning platforms, virtual reality (VR) applications, and AI-driven analytics. Ambe et al. (2024) studied the use of electronic media in environmental education within Nigerian tertiary institutions and found significant adoption, though limited by resource constraints. Their work is grounded in constructivist theory, which suggests that learners actively build knowledge through interactive use of digital tools.

Similarly, Achebo (2022) examines the development of digital ecosystems across Africa, noting that they help in addressing systemic educational challenges by balancing biotic elements (teachers, learners) with abiotic ones (infrastructure, platforms). Persistent challenges, however, include unreliable electricity supply and low digital literacy levels, especially in rural Nigerian communities.

Allam et al. (2025) further identify five transformative trends in education: shifting aims, ecologies, evolving teaching and learning processes, and redefined governance structures. These trends highlight how digital technologies such as AI which can contribute to sustainable educational futures, including personalized models of governance.

Digital Technology in Nigerian Education

Existing literature on Nigeria emphasizes both the potentials and limitations of digitalization. Mba and Adieme (2024) focusing on secondary education in Imo State, recommend policy interventions aimed at improving digital infrastructure and teacher competence to advance sustainable development goals. Alenezi et al. (2023) outlines persistent obstacles in Nigerian higher education, such as inadequate connectivity and high internet costs, but also identified promising opportunities in flexible and collaborative learning models.

Azubuike et al. (2021) document how the COVID-19 pandemic exposed digital divides, showing that students in government schools faced disproportionate barriers to online learning, and often tied to their parental education levels. To address such disparities, frameworks like the Professional Development Framework for Digital Learning emphasize the importance of teacher training and the application of Technological Pedagogical Content Knowledge (TPACK). Building teacher capacity is viewed as a critical step for advancing digital learning in Nigeria.

Benefits of Digital Technologies in Education

Research identified multiple benefits that can significantly transform teaching and learning process through the use of digital technology in inclusive education Navas-Bonilla et al. (2025). They enhance participation by promoting collaboration and interaction, creating dynamic and inclusive learning environments. With diverse digital resources, students gain access to various updated knowledge that stimulates the development of critical and analytical thinking.

Lusigi (2019) conducted a study on how the use of ICT improved educational quality not only by broadened access to distance education but also by enhancing "learning productivity" this is achieved via optimizing costs and tailoring instruction to labor market and community needs, thereby equipping learners with immediately applicable in specialized environments. Similarly, Kim and Higgs (2023) found that digital platforms help future teachers form stronger and meaningful connections with their students. This approach promoting a deeper understanding of literacy in the digital context and emphasizes the potential of technology to address cultural and racial gaps in education. Collectively, these studies highlight the role of technology can be a powerful catalyst for inclusive, equitable, and high-quality education, preparing learners to be effective citizens for an interconnected global society.

Concept of University–Industry Collaboration

University–industry collaboration (UIC) represents a strategic partnership between higher education institutions and industrial organisations aimed at promoting the exchange of knowledge, expertise, and technology to promote innovation

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and socio-economic advancement (Rossoni et al., 2024). The primary objective of UIC is to stimulate innovation through the sharing of knowledge and the application of research outcomes to address real-world industrial challenges. In an increasingly dynamic and competitive global economy, such collaborations have become essential as they enable the integration of academic research with industrial practice, leading to the development of new technologies and processes that enhance productivity and competitiveness (Samuel & Omar, 2015).

UIC serves as a vital link between theoretical research and practical application, establishing a bridge that facilitates the translation of academic discoveries into tangible outcomes. This interaction is founded on a shared commitment to achieve mutual objectives by promoting research collaboration and technological exchange that promote innovation, productivity, and sustainable development (Wirtz & Langer, 2025). According to the Organisation for Economic Co-operation and Development (2019), universities play a crucial role in generating new knowledge and equipping a skilled workforce essential for knowledge-based economies. The industrial sector, in turn, functions as both a recipient and an implementer of academic innovations, serving as the platform where new technologies and research findings are tested and commercialised (Sutrisna et al., 2021).

The collaboration between academia and industry is widely recognised as a major driver of innovation, competitiveness, and technological advancement (Ankrah & Omar, 2015; Evans et al., 2023; Lundberg & Öberg, 2021). The industry transforms research outputs into market-ready products and services, thereby serving as a conduit through which scientific knowledge contributes to economic development (Mirza et al., 2020). Scholars have identified diverse forms of university–industry collaborations that vary in approach, duration, objectives, and expected outcomes (Ankrah & Omar, 2015; Evans et al., 2023). The most frequently cited forms include knowledge transfer through product development and commercialisation, academic consulting, joint research and development, funding through endowments or trusts, joint authorship of scholarly works, symposia, sabbaticals in industry, and the employment of university graduates (Rossoni et al., 2024; Ankrah & Omar, 2015).

Furthermore, research indicates that both academia and industry derive mutual benefits from such collaborations. These benefits include access to new knowledge, expertise, technology, and the application of research findings to address practical problems and promote innovation (Figueiredo & Ferreira, 2022). Such partnerships not only enhance innovation capacity and economic growth but also strengthen the global competitiveness of both sectors. Through collaboration, industry partners gain insights into emerging technologies and access to specialised facilities, while universities increase their opportunities for publication, patent generation, and the commercialisation of research through spin-offs and licensing. Additionally, such engagements encourage academic researchers to contribute towards national development, job creation, and wealth generation, thereby reinforcing the strategic role of UIC in socio-economic transformation (Bastos et al., 2021).

Government Policies on University–Industry Collaboration (UIC)

Conventionally, universities have been established to provide education and to produce graduates who meet the global demand for skilled professionals in both industrial and public sectors. Collaboration between academia and industry has increasingly become an essential component of efficient national innovation systems. It is therefore important to note that governments play a crucial role in promoting University–Industry Collaboration (UIC) through the creation of enabling environments, reliable funding mechanisms, and support for research and development (R&D), innovation, economic growth, regulatory reforms, grants, and institutional development. These policy instruments are essential to ensuring that universities and industries can jointly contribute to national development.

Furthermore, part of the policy responsibility of governments involves the

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provision of essential infrastructure and intermediary institutions such as Technology Transfer Offices (TTOs), technology parks, innovation hubs, and business incubators that strengthen collaboration and innovation ecosystems. Governments can also facilitate collaboration through subtle mechanisms, including offering targeted support services to universities and industries as they seek potential partners, engaging in outreach activities, and encouraging networking that enhances the spirit of cooperation and knowledge sharing. Such initiatives promote the understanding that collaboration between academia and industry is mutually beneficial and fundamental to technological advancement and national development (Bastos et al., 2023).

Globally, several governments and multinational organisations have formulated and implemented diverse policy frameworks aimed at strengthening UIC. For example, the Organisation for Economic Co-operation and Development (OECD) developed policy instruments that evaluate and support science–industry knowledge transfer among member nations. Similarly, the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022 in the United States allocated billions of dollars to enhance R&D partnerships between universities and industries (OECD, 2022; United States Congress, 2022). Governments also support collaboration through funding mechanisms such as grants, tax credits, and subsidies in specific sectors to promote R&D activities. They further establish policies on intellectual property (IP) rights to guarantee ownership, fair benefit sharing, and commercialisation rights of innovations, thereby promoting mutual trust between universities and industries. Additionally, the creation of science parks and innovation hubs provides shared physical spaces for universities and industries to co-locate, exchange knowledge, and explore collaborative opportunities.

In Africa, contextual policy reforms have also been introduced to promote UIC as part of broader national development agendas. For instance, South Africa's Technology Innovation Agency (TIA) facilitates funding for commercially viable R&D projects, while the Department of Science and Innovation (DSI) supports linked research chairs in universities to promote industry-driven research (Department of Science and Innovation, 2021). Many scholars have similarly emphasised the importance of strong partnerships between universities, industries, and government agencies in driving innovation and knowledge transfer (Adebayo & Moyo, 2023). Bastos et al. (2023) further observed that over the past five decades, government policies and initiatives have played an instrumental role in shaping the growth of UICs globally.

In Nigeria, several policy initiatives and reform programmes have been established to encourage UICs and strengthen the connection between universities and industries. Prominent among these initiatives is the Tertiary Education Trust Fund (TETFund), which provides financial support for quality education, training programmes, and research grants, and also enhances infrastructural development in tertiary institutions. TETFund promotes collaboration between universities and industries by funding industry-related research projects that promote innovation and technological advancement (TETFund, 2023). Similarly, the Industrial Training Fund (ITF) was established to facilitate industrial training placements for students, thereby enabling practical, hands-on experience within industries. The National Science, Technology and Innovation Policy also promotes the establishment of technology transfer offices within universities, while the 1986 National Science and Technology Policy was developed to encourage R&D projects and support the transformation of research outcomes into commercially viable products (Federal Ministry of Science, Technology and Innovation, 2020). Through these efforts, the Nigerian government continues to promote an innovation-driven economy by supporting collaboration between academia and industry, which is vital for sustainable development, knowledge transfer, and the commercialisation of research outcomes.

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Historical Development Process of University–Industry Collaboration (UIC) Models

The development of University–Industry Collaboration (UIC) models can be traced back to the late nineteenth century in the United States, where partnerships began primarily in the field of agriculture. These collaborations emerged between land-grant universities and local industries, often in an informal manner, with a major focus on consultancy services. Universities provided enlightenment to farmers and involved students in practical fieldwork to gain hands-on experience. This early interaction relied on local government funding and the decentralisation of higher education institutions, which enabled universities to address regional industrial needs and promote innovation within local economies (Etzkowitz & Zhou, 2017).

At the beginning of the twentieth century, collaboration expanded into scientific and engineering fields, driven by mutual interest in solving practical problems and promoting technological advancement. The establishment of the Research Corporation in 1912 marked a milestone in early technology transfer (TT) initiatives, as it managed patents originating from university research. Although its scope was initially limited, the proceeds generated from these patents were reinvested to support further scientific research, thereby reinforcing the relationship between academia and industry (Mowery & Sampat, 2005).

Between the late 1920s and 1930s, UIC models became more structured and institutionalised. Significant progress was achieved in chemical engineering through collaborations anchored on shared resources and expertise. During this period, several formal educational partnerships were formed, and the Research Corporation expanded its technology transfer role to manage patents for additional universities. While the growth of UICs in Europe was slower, early research collaborations in the physical sciences laid the foundation for subsequent advancements in academic–industrial partnerships across the continent.

By the end of the twentieth century, numerous policy interventions were introduced to strengthen the link between universities and industries. Among the most influential were the 1980 Framework Programmes in Europe, which promoted collaborative research and resource sharing, and the Bayh–Dole Act of 1980 in the United States, which allowed universities to retain intellectual property rights for federally funded research. These legislative frameworks encouraged the commercialisation of academic research outputs and significantly boosted innovation-driven economies. Around the same period, the Triple Helix Model was conceptualised, introducing a dynamic framework for understanding the interactive roles of universities, industries, and governments in innovation systems (Etzkowitz & Zhou, 2017).

In Europe, subsequent initiatives such as the Lisbon Strategy (2005–2010) and the University–Business Forum (2008–present) further reinforced collaborative models, particularly those that focused on educational partnerships, student engagement, and curriculum alignment with industrial needs. These programmes provided platforms for dialogue between academia and industry, ensuring that university education remained responsive to the evolving demands of the labour market and technological innovation.

The twenty-first century ushered in a new era of interconnected and flexible UIC models, largely shaped by digital transformation and the global knowledge economy. Modern collaborations now include public–private partnerships, open innovation platforms, research consortia, and entrepreneurial university models that integrate education, research, and commercialisation activities. These models have been instrumental in promoting innovation ecosystems, yet they face challenges such as cultural differences between academia and industry, intellectual property disputes, and research integrity concerns. Addressing these challenges requires comprehensive policy frameworks and institutional strategies that balance academic freedom with industrial expectations while promoting trust, transparency, and sustainability in collaboration (D'Este & Perkmann, 2011).

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Models of University–Industry Collaboration (UIC)

University–Industry Collaboration (UIC) models represent structured frameworks for establishing and managing cooperative relationships between academic institutions and industrial firms. These models are designed to promote mutual benefits such as knowledge transfer, innovation, skill development, and economic growth. Each model varies depending on the nature of the partnership, the degree of engagement, and the intended outcomes (Ankrah & Al-Tabbaa, 2015).

Some of the most recognised UIC models include the following:

The Triple Helix Model

The Triple Helix Model illustrates the collaborative interaction among universities, industries, and governments as drivers of innovation and socio-economic development. This model emphasises that the synergy among the three entities promotes the creation of new knowledge, technologies, and innovative practices. Over time, the model has evolved to include hybrid organisations such as Technology Transfer Offices (TTOs), science parks, and innovation hubs, which serve as facilitators for effective collaboration and commercialisation of research outputs. The Triple Helix approach underscores that innovation thrives when there is constant interaction and shared responsibility among academia, industry, and government (Etzkowitz & Zhou, 2017).

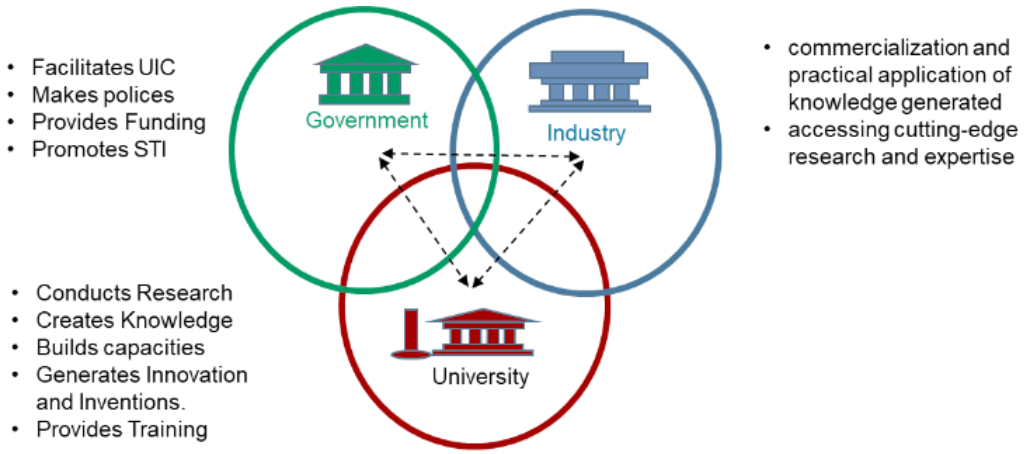

Figure 1: Triple Helix Model Conceptualizing UIC

The Network Model

The Network Model underscores the importance of relationships, social capital, and communication channels in facilitating effective University–Industry Collaboration (UIC). The model is premised on the assumption that collaboration is best sustained through trust, mutual understanding, reciprocity, and shared objectives between universities and industrial partners. It highlights that the success of such collaborations largely depends on interpersonal and institutional networks that enable the free flow of knowledge and innovation (Mora-Valentín et al., 2004).

Furthermore, the model emphasises the role of intermediaries—such as Technology Transfer Offices (TTOs), innovation hubs, and research centres—as essential facilitators in bridging the gap between academic research and industrial application. These intermediary institutions help coordinate collaborative projects, ensure effective communication, and build trust between partners. Consequently, networks form the backbone of sustainable innovation ecosystems by promoting multi-level interactions

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across academia, industry, and government (Ankrah & Al-Tabbaa, 2015).

The Evolutionary Model

The Evolutionary Model views UIC as a dynamic, adaptive, and continuous process that evolves through several developmental stages. These stages—commonly identified as embryonic, initiation, engagement, and established phases—demonstrate how collaboration matures over time as trust, shared vision, and mutual benefit deepen (D'Este & Perkmann, 2011).

This model also acknowledges the existence of facilitators and barriers that influence each stage of collaboration. Among the key facilitators are effective communication, joint problem-solving, and institutional support, while obstacles often include intellectual property disputes, lack of trust, and differences in organisational culture. The model, therefore, underscores that successful collaboration requires adaptive mechanisms and mutual learning processes that evolve in response to emerging challenges and opportunities (Plewa et al., 2013).

The Collaborative Model

The Collaborative Model is characterised by the establishment of dedicated research centres or hubs that promote joint decision-making, shared funding, and resource pooling between universities and industries. This model is particularly effective for long-term strategic partnerships that require sustained investment in research, development, and innovation. Within this framework, both partners contribute expertise, share risks, and co-develop solutions that address sectoral and societal needs (Bruneel et al., 2010). By promoting deeper engagement and joint ownership of outcomes, the model enhances knowledge exchange and ensures that research outputs have practical value. Collaborative research hubs, for example, create an environment where academics and practitioners work side by side, promoting innovation-driven growth and talent development within both sectors.

The Technology Transfer Model (Entrepreneurial Universities)

The Technology Transfer Model, also referred to as the Entrepreneurial University Model, focuses on the commercialisation of academic research outcomes. In this model, innovations such as software, prototypes, and new technologies developed within universities are transferred to the marketplace through mechanisms like patenting, licensing, and spin-off companies (Siegel & Wright, 2015). This approach enables industries to access new technologies while providing universities with alternative revenue streams through royalties and revenue-sharing agreements. Consequently, universities become active economic actors, contributing directly to regional and national development by transforming scientific research into commercially viable products and services. The model also supports entrepreneurship within academia, thereby strengthening the innovation capacity of higher education institutions (Guerrero & Urbano, 2012).

The Open Innovation Model

The Open Innovation Model promotes knowledge sharing, collaboration, and co-creation across institutional boundaries. Unlike traditional closed systems of innovation, this model encourages the exchange of ideas, technologies, and organisational resources between universities, industries, and other stakeholders to solve complex global challenges (Chesbrough, 2003). Digital tools, crowdsourcing platforms, and collaborative networks are often used to facilitate open innovation, allowing multiple actors to contribute diverse perspectives. The model prioritises transparency, knowledge co-production, and multi-stakeholder participation, ensuring that both academic research and industrial practice benefit from shared learning and innovation. Through such openness, universities and industries can jointly develop sustainable solutions that respond to the demands of a rapidly evolving digital economy (West & Bogers, 2014).

Other UIC models have been proposed in the literature (Ankrah & Omar, 2015; D'Este &

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Perkmann, 2011). However, the selection of a particular model largely depends on the objectives, resources, and contextual realities of the participating institutions. Collectively, these models illustrate the diversity and complexity of university–industry relationships and demonstrate their potential to drive innovation, enhance knowledge transfer, and promote socio-economic growth. Each model presents unique advantages and limitations, but all share a common goal: the alignment of academic research and industrial needs to promote sustainable development and address complex societal challenges.

Challenges in Nigeria's Context

Educational technology faces challenges in Nigeria, particularly in access and implementation. Concerns include excessive screen time, unequal access to devices, and limited teacher training. The COVID-19 pandemic further highlighted the importance of digital learning, requiring teachers to create online content and guide students in analyzing a topic from different angles. Moreover, some students thrive in online, others struggle due to lack of support or difficulties with traditional schooling. For instance, a learner who faced some difficulties in physical setting may face more in the current situation. For learners from disadvantaged backgrounds, limited access to devices and the internet further widens inequality (Bennett et al., 2012; Seale et al., 2021; Shilpa et al., 2021).

Evidently, Affordable low-tech approaches, such as "instruction at the appropriate level," have shown positive outcomes and may be more viable for resource-constrained nations which need to investigate to find out whether high-tech or low-tech solutions are better or not. Yet, challenges remain, online classes often fail to replicate face-to-face engagement, MOOCs tend to exclude younger learners, and practical-based courses are harder to teach online. Furthermore, many students lack internet accessibility devices, and younger users often face health issues like poor eyesight and back strain. Teachers, too, may be inexperienced with digital tools, complicating online delivery. Nevertheless, they make significant efforts to adapt (Başal & Eryılmaz, 2021; Masters et al., 2016). College students who take more practical subjects than theoretical subjects face similar challenges because practical knowledge is not attainable in online programmes (Criollo-C et al., 2021; Njoku, 2015).

Global view also provided lessons as noted by Zhou et al. (2024), in a review of Chinese music teaching materials, show how localized digital content evolves to fit cultural contexts offering classes for Nigeria in integrating technology into its education system. The following section presented discussion of the article.

DISCUSSION OF FINDINGS

The conceptual article titled "Sustainable Learning Ecosystem: A New Digital Media Technology Approach for Nigeria" avails the contemporary framework for digital technology for addressing contemporary issues bedeviling education system in Nigeria. The article drew from extant multi-disciplinary literature an integrated SLE that encompasses emerging digital media technologies – VR, AI, IoT and e-learning platforms that facilitate adaptive, inclusive and ecologically sustainable education in Nigeria. The integration of digital media technology into Nigerian education for sustainability is summarized in table 1

Table 1: Sustainable Technology Integration

Components	Technology	Sustainability Feature	Nigerian Adaptation
Digital resources	All Apps, AI Tutors	Low Bandwidth; open education resource (OER)	Local/international Language Interfaces
Physical environments	IoT Equipment; Solar Kits	Energy Efficiency	Rural Hub Models

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Components	Technology	Sustainability Feature	Nigerian Adaptation
Pedagogies	Gamification Platforms	Adaptive algorism	Cultural Content Integration
Communities	Social Media Forums	Inclusive Access	Support Local Support

Source: Authors Generation, 2025

This is in line with SDGs 4 and 13 that deals with 'Quality Education' and 'Climate Action' respectively. They stressed on increased learning autonomy, reduced resource dependency and community participations. The main contribution of this article is its ability to synthesize theories of connectivism, systems theory, ESD and adaptive learning, followed by presentation of adapted model for Nigerian context, that characterized infrastructural insufficiencies and digital inadequacies, posed by post-COVID-19 challenges.

The article has comprehensively grounded SLE framework to four theories, providing a comprehensive conceptual framework. Connectivism is regarded as key to digital learning where knowledge is derived from networked connections instead of isolation (Bell, 2011; Boyraz & Ocak, 2021). This corroborated to with the Nigerian demand for scalable, cost-effective digital tools, such as MOOCs, YouTube, AI-driven contents as well as other social media platforms for efficient knowledge transmission (Mehmood & Haroon, 2025; Mutiga, 2023). System theory was also traced to GST of Bertalanffy, which views education as an inter-dependent learning ecosystem, adaptability, feedback-loops and emphasizing holism as key components for integrating human and infrastructure components of fragmented education system in Nigeria.

Consequently, ESD theory drawn from UNESCO extends the framework to the level of transformative learning, competency promotion to address climate and inequality challenges. The article relevance to SETS model (Gomaa & Gauthier, 2024) is novel, to promoting eco-designed EdTech for the minimization of negative environmental impact. Finally, the adaptive learning theory stressed on customization of learning through AI, aligning to constructivist influence to converge diverse needs of learners and school drop-outs reduction (Rincon-Flores et al., 2024).

The article was able to incorporate multi-disciplinary syntheses, which refined diverse approaches to reflect global contemporary complexities. For example, the four SLE dimensions (relearning & renewing, independent and collaborative learning, Active learning with orientation and transferability) provide a practical guide, supported by feedforward and self-assessment mechanisms (Bouzid et al., 2025; Burke, 2021). By this empowerment, learners in Nigeria can survive technological transitions from formal education to the competitive workforce demand, promote sustainable skills within the dynamic technological challenges.

However, the article relied on theoretical abstractions of highlighting contextual boundaries. For instance, connectivism assumes network reliability, and yet the instability power supply and low digital literacy in Nigeria could make networked learning inaccessible, widening the divide instead of bridging it (Ajamu et al., 2023). Systems theory stressed on equilibrium, but overlooks the dynamics of power, such as rural-urban disparities and gender differences with respect to technological access (Azubuike et al., 2021). Moreover, while ESD supports ethical use of technology, the article did not sufficiently addressed concept of e-waste Management in Nigeria, where the low practice heavily contributed to environmental degradation (Hashim et al., 2025). Adaptive learning- AI focus might overlook relevance of culture as a global mechanism and fails to integrate local languages and curricular, resulting to 'digital colonialism' in the context of Africa.

Benefits and Challenges Assessment

It is evident that the article highlighted enormous benefits of new digital media technologies (VR and AI analytics), including

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improved accessibility, reduced environmental wastages via paperless processes (Alam & Mohanty, 2023; Ambe et al., 2024). In the Nigerian context, these could reduce climate vulnerabilities leading to dropouts by enabling remote virtual learning, as demonstrated during COVID-19 (Abubakar & Ekele, 2025; Ajamu et al., 2023; Javaid et al., 2020; Kosaretsky et al., 2022). Collaborative platforms also aligned with SDGs, promotion of global inclusiveness and competitiveness by shifting from teacher-centric to the modern learner-driven models (Almalki et al., 2025; Carvalho et al., 2022; Chukwuemeka et al., 2025).

Yet, the challenges are well-established but lack in-depth explorations. The persistent high cost and unequal access to internet, in addition to the infrastructural decay which severely affect rural areas (Alenezi et al., 2023; Mba & Adieme, 2024). The article highlighted unnecessary screen time and health issues (Shilpa et al., 2021), while downplays the socio-economic factors like parental level of education that influence online engagements (Azubuike et al., 2021). Comparatively, China has localized its digital contents (Zhou et al., 2024), suggesting that Nigeria can emulate similar strategy.

Limitations

The conceptual article, comprehensively synthesized theories, methodologies as well as frameworks with an attempt to develop sustainable learning ecosystem with the help of new digital media technologies for Nigerian education system, might not lack inherent limitations. The limitations must be acknowledged to further serve as guide future studies.

First, the study is primarily conceptual, which exclusively relied on secondary sources that synthesized multi-disciplinary perspectives and proposed theoretical framework, did not use primary data (survey or interview) that can inform empirical validation within the Nigerian tertiary institutions. As such, the propose, framework comprises of elements such as digital resources, pedagogies, physical environment and community participation were not tested in real-world contexts.

Second, reliance on the extant literature may leads to selection bias tendency. So, the inclusion criteria for the study focused only on publications related to modern digital trends which may overlook other foundational research predating the year 2016 that could deepen historical discuss on challenges of education in Nigeria. Further, the literature was drawn for local and international sources, the reviewed theories only emphasized on global theories (connectivism, systems theory, ESD, and adaptive learning) which may not fully account for the economic, socio-cultural and political peculiarities of Nigeria. For example, the underlining assumption of theory of constructivism – reliable network connectivity as well as high digital literacy are noted as serious challenges in the contextual realities of Nigeria, in addition to unreliable power supply digital divide and infrastructural decay.

Third, the article does not deeply explore certain critical issues that could impact the sustainability of the proposed ecosystem. For example, while environmental sustainability is a main theme allied with SDGs 4 and 13, the discussion on e-waste management is limited, despite Nigeria's documented challenges with electronic waste from imported or discarded digital devices (Hashim et al., 2025). Similarly, risks of "digital colonialism"—where global technologies impose foreign cultural norms and marginalized local languages or indigenous knowledge—are acknowledged but not thoroughly analysed. Gender disparities, parental education levels influencing access (Azubuike et al., 2021), and health concerns from excessive screen time (Shilpa et al., 2021) are mentioned but need more in-depth analysis, particularly in a Nigerian where socio-economic factors strengthen these problems.

Fourth, the article's scope lies mainly on higher education and tertiary institutions, with little attention to primary and secondary schools, where the foundation for digital literacy is established. This narrow scope may limit the framework's generalizability across the wider educational spectrum, particularly given Nigeria's significant

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dropout rates in earlier stages affected by climate pressures and resource constraints (Abubakar & Ekele, 2025).

Finally, being a conceptual synthesis, the study omits quantitative analyses such as cost-benefit assessments of infrastructure investments or predictive modeling of adoption patterns using systems theory approaches like causal loop diagrams. This gap could weaken the ability of policymakers to prioritize interventions effectively.

CONCLUSION

The article discussed digital media technology for sustainable learning ecosystem for Nigerian tertiary education. New media learning tools, sustainable learning theories, learning pedagogy, learning ecosystem, learning infrastructure, challenges and benefits to Nigerian education system.

The study adequately studied the availability and utilization of e-learning technologies for teaching environmental education in Nigerian tertiary institutions. The investigation discovered that there exist e-learning technologies specifically created for environmental education pedagogy in the studied location. This conclusion shows that there is an opportunity to include cutting-edge digital tools and resources into the teaching process. However, the study's findings suggest a worrying conclusion: rather than being supported or offered by institutions, these e-learning platforms are primarily owned and used by individual lecturers. Because the lecturers' resources and personal attention are critical to the proper use of these technologies, this scenario raises severe concerns about their long-term survival.

The interplay between all these will invariably help to improve the Nigerian education ecosystem to a better equitable, inclusive, accessible, removing knowledge barrier and inquisitive system that can blend the diverse capabilities of students. The approach promote personalized innovation, academic development, strengthen critical thinking and cognitive skills such as creativity, autonomy and problem solving education.

Finally, the integration of these approaches in education extend beyond just adapting to individual needs. It is also a significant step toward creating an educational system that values diversity and allows student to attain their self-actualizations. These technologies revolutionize the educational environment by promoting fair and accessible learning, opening up new opportunities for inclusive education in the future. Collaboration among governments, educational institutions, and the commercial sector is critical to the successful attainment of technology-driven education in Nigeria.

RECOMMENDATIONS

Based on the findings of the study, the following recommendations were offered for future studies, particularly in the context of new digital media technology for sustainable learning ecosystem, which have the potential to significantly improve educational standard of the Nigerian tertiary institutions.

First, funding for revitalizing education must be adequately provided by the federal and state governments as well as private owners to support the implementation of e-learning technologies in their institutions. This includes the cost of the necessary digital and electronic equipment and software, alongside the required infrastructure to enhance smooth learning experiences. To level the playing field for students across the nation, all higher institutions must have access to cutting-edge technology. Without this financial commitment, e-learning potential to reduce educational gaps would not be fully attained.

Second, as an alternative solution, federal and state governments, as well as proprietors could consider subscribing for internet access and other e-learning equipments and digital resources that individual instructors use for teaching, learning and research. This temporary solution can relieve financial strain on teachers and encourage them to continue their e-learning endeavors. It is critical to ensure that financial constraints do not inhibit effective implementation of e-learning initiatives.

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Third, it is critical for tertiary institutions, lecturers and students to stay up-to-date on new digital media technologies for e-learning and integrate them as teaching and learning strategies. Attaining quality and functional education requires being familiar with new tools and practices of the technology field that is rapidly evolving. To ensure that the technological advancement can provide students with efficient and modern educational experiences, institutions, lecturers and students should involve in e-learning based training, professional and academic development programmes. Institutions and lecturers may design and implement interactive, enabling learning ecosystems that meet the adequate requirements and needs of modern-day students by adopting e-learning tools. Implementing these recommendations will provide the potential for complete change of the educational ecosystem of higher institutions in Nigeria. The adoption of impactful projects of such can be enhanced through providing functional policies for transformation of education.

Fourth, the set objectives of this article were met through the highlight of recommendations such as infrastructure investments, teacher training, and stakeholder collaborations, which can be realistic by reformation to harness the Nigerian youthful population "green transformation". The refined framework could be extended to integrate phase implementation as (i) short-term – prioritization of teacher training via a free MOOCs programme and partnership with platforms such as Coursera or local initiatives of National Open University Nigeria (NOUN) to improve digital literacy through community hubs that support solar-powered digital devices (ii) medium-term – investing in a localized EdTech and AI tools that support local languages to reduce cultural barrier. As a policy, school should also be mandated to paper recycling to align with ESD (iii) long-term – public-private partnership (PPP) with Google and telco companies should be encouraged for infrastructure, in line with system theory feedback loop for adaptability.

Finally, future studies should address these gaps by exploring mixed-methods research, including action-based pilot programmes, to empirically examine the framework, evaluate its long-term result, and adapt it for broader use beyond Nigeria to other developing countries within sub-Saharan Africa.

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