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Science Education in the Digital Era: Socioeconomic Barriers, ICT Integration and Emerging Gaps in Teaching and Learning

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Abstrak : The rapid advancement of digital technologies has reshaped educational practices globally, yet science education in Nigeria continues to face systemic challenges in adapting to this shift. Persistent infrastructural gaps, economic constraints, and disparities in teacher preparedness raise critical questions about how effectively digital tools can enhance science learning. This research aimed to explore the opportunities and challenges of integrating information and communication technologies (ICT) into science education in Nigeria, with a focus on understanding how digitalisation shapes access, pedagogy, and equity. The research employed a qualitative, document-based method. It synthesised findings from peer-reviewed scholarship, policy documents, and national education reports through thematic analysis, allowing for the identification of recurring patterns and emerging trends in the digital transformation of science classrooms. The results show that ICT adoption in Nigerian science education is real but uneven. Three main findings emerged: socio-economic and infrastructural barriers—such as unreliable electricity, limited internet access, and household poverty—restrict effective ICT use; while some teachers employ digital tools, their application is often limited to surface-level tasks rather than transformative, inquiry-based science learning; and new divides are emerging, as digital resources remain concentrated in urban and private schools, leaving rural and disadvantaged groups further behind. In conclusion, this research contributes by framing ICT integration not as an isolated technical issue but as an interconnected system of socio-economic, infrastructural, and pedagogical factors. Its value lies in highlighting science-specific digital needs and proposing a holistic perspective that can inform policies and practices aimed at fostering inclusive, equitable, and effective science education in the digital era.

Keywords: Science Education, ICT Integration, Digital Divide, Socio-Economic Barriers

INTRODUCTION

Science education has long been recognised as the bedrock of technological advancement and national development. In Nigeria, as in many countries, the teaching of science is expected to cultivate critical thinking, innovation, and problem-solving skills among students (Jolaoluwa et al., 2024; Olofin et al., 2023). However, the context of science education has been significantly reshaped by the rise of the digital age. The increasing availability of digital tools, such as virtual laboratories, computer simulations, and online learning platforms, is transforming how scientific concepts are taught and learned (Potkonjak et al., 2016; Poultsakis et al., 2021). Globally, schools are moving beyond chalkboards and static textbooks to adopt digital pedagogies that bring abstract scientific principles to life. In Nigeria, this transformation is especially important because of persistent challenges in traditional science teaching, such as inadequate laboratory facilities, large class sizes, and limited resources for experimentation (Emeka et al., 2021). ICT offers opportunities to bridge these gaps, enabling learners to visualise complex ideas, conduct simulations where real experiments are not feasible, and access a wealth of global knowledge resources (Mhlongo et al., 2023). In essence, the digital era holds the promise of democratizing access to quality science education and equipping learners for the demands of the 21st-century economy.

Across the globe, there is a strong policy and research consensus on the need to integrate digital technologies into education systems. Reports by UNESCO and the World Bank argue that ICT in education is no longer optional but central to achieving inclusive and equitable quality education, as outlined in Sustainable Development Goal 4 (SDG 4) (Samarakoon et al., 2017). This global momentum intensified after the COVID-19 pandemic, which exposed vulnerabilities in traditional education systems and accelerated the adoption of digital learning worldwide. Nigeria's rationale is compelling due to its growing youth population, high science enrollments, and the necessity of a digitally literate workforce for global economic competition (Bello & Ajao, 2024). The Federal Government has responded with policies such as the National ICT in Education Policy, which emphasises the integration of ICT into science teaching at all levels (Richard, 2021). Yet, despite these efforts, the reality on the ground reflects uneven adoption, highlighting the need for a critical examination of what facilitates or hinders effective ICT use in science education. This research aligns with both global imperatives for digital transformation and national priorities for strengthening science education. By analysing socio-economic barriers, pathways of ICT integration, and emerging gaps, the research contributes not only to academic debates but also to practical solutions for Nigerian policymakers, educators, and development partners.

Statement of the Problem

Despite its potential, science education in Nigeria continues to face deep-seated challenges that limit the benefits of ICT integration. First, socio-economic barriers such as poverty, unreliable electricity supply, inadequate infrastructure, and rural–urban disparities restrict both teachers' and students' access to digital resources (Mohammed & Edu, 2021). Second, while ICT integration has been promoted through initiatives such as digital classrooms and online platforms, these efforts remain fragmented. Teacher training often emphasises basic computer literacy rather than subject-specific pedagogy, leading to superficial use of ICT (e.g., PowerPoint slides) rather than transformative practices that foster inquiry-based science learning (Obada et al., 2023). Finally, there are emerging gaps that threaten to widen inequalities. Digital tools, if unevenly distributed, risk reinforcing social divides between urban and rural schools, private and public institutions, or boys and girls. Without deliberate strategies for inclusivity, ICT adoption may create a two-tier system where some learners advance rapidly while others are left behind (Okudolo & Ojakorotu, 2021). Moreover, the gap between policy aspirations and classroom realities remains wide, as ambitious national ICT frameworks often outpace the resources and support available to schools. Thus, the problem is not the absence of ICT policy or awareness in Nigeria, but the misalignment between opportunity and accessibility. Unless socio-economic barriers are addressed, teacher preparation is strengthened, and equity gaps are closed, science education in Nigeria risks missing out on the full promise of the digital age.

Research Objectives

This paper is guided by three core objectives:

1. To identify the socio-economic barriers—such as infrastructure, income, and regional disparities—that hinder equitable ICT-enhanced science education in Nigeria.
2. To examine the current extent and quality of ICT integration in Nigerian science classrooms, including digital tools, teacher capacity, and policy efforts.
3. To uncover emerging gaps in teaching and learning, arising from uneven integration—such as equity concerns, pedagogical misalignment, and mismatches between policy aspirations and classroom realities.

Literature Review

Science education in Nigeria has long been regarded as a driver of modernisation and national development. Since the introduction of Western-style schooling during the colonial period, emphasis has been placed on producing graduates capable of supporting agricultural, medical, and industrial needs (Umoh, 2012). However, post-independence reforms revealed persistent shortcomings in science teaching, particularly inadequate laboratory facilities, poor teacher preparation, and rote-learning pedagogies (Fafunwa & Aisiku, 2022). Contemporary assessments, such as the National Examinations Council (NECO) and the West African Examinations Council (WAEC), consistently highlight underperformance in core science subjects like Physics, Chemistry, and Biology (Anthony, 2021). Researchers link this to structural issues—such as overcrowded classrooms and poor funding—and outdated teaching methods that fail to spark curiosity or problem-solving (Okpara & Ezeador, 2024). Within this context, the digital age has emerged as both a challenge and an opportunity to revitalise science education.

Globally, ICT has been celebrated as a transformative force in pedagogy, offering simulations, interactive experiments, and access to vast digital resources (Alam & Mohanty, 2023). The United Nations Educational, Scientific and Cultural Organisation emphasises ICT integration as central to achieving inclusive and equitable quality education, especially under the Sustainable Development Goal 4 agenda (Costa et al., 2024). In Nigeria, the National Policy on Education recognises ICT as a vital tool for enhancing teaching and learning, while the National ICT in Education Policy outlines strategies for deploying digital infrastructure and training teachers. Pilot projects, such as the Lagos Eko Project and UNESCO's ICT Teacher Training initiatives, show pockets of success in urban centres (Oyekanmi, 2016). However, large-scale studies suggest ICT integration remains inconsistent, particularly in rural and public schools (Oshowole, 2024). Teachers often use ICT tools for administrative tasks or surface-level teaching aids (like PowerPoint presentations), rather than for inquiry-driven or interactive learning. This pattern reflects what Ndjama (2025) described as "second-level digital divides"—where access exists but is underutilised in pedagogically meaningful ways. For Nigerian science classrooms, this means digital resources often supplement but do not fundamentally transform teaching and learning.

Despite policy enthusiasm, socio-economic realities present formidable obstacles to ICT adoption in science education across Nigeria. Several barriers recur in the literature: Schools, especially in rural areas, lack reliable electricity, internet access, and functional computer laboratories (Oshowole, 2024). Without these, ICT-based science instruction remains aspirational. With nearly 40% of Nigerians living below the poverty line, families struggle to afford digital devices or internet subscriptions (Uzuegbunam, 2019). Consequently, students from wealthier urban schools enjoy greater exposure, widening inequalities. Studies reveal that many science teachers receive insufficient training in digital pedagogy. Teacher education programs often focus on basic ICT literacy rather than subject-specific applications for science teaching (Isa, 2022). This limits teachers' confidence and creativity in integrating digital tools into their lessons. While national policies outline ambitious digital learning goals, implementation is slowed by inadequate funding, bureaucratic hurdles, and limited monitoring mechanisms (Agbovu & Chukwuma, 2025; Okonkwo, 2024). These barriers show that Nigeria's ICT in education challenges are not simply technological but deeply intertwined with socio-economic realities.

The promise of ICT is accompanied by emerging challenges that, if not addressed, may reinforce rather than reduce inequality. Literature identifies several critical gaps: Unequal access between private and public schools, and between urban and rural areas, risks entrenching a two-tier education system (Mathew et al., 2025; Okudolo & Ojakorotu, 2021). For instance, private schools in Lagos often deploy smart classrooms, while public schools in northern states struggle with chalkboards. Studies indicate that female students often face greater barriers to digital learning due to socio-cultural norms and reduced access to technology at home (Kemi, 2023; Oshowole, 2024). This threatens inclusivity in science education, where girls are already underrepresented. Digital tools, when not integrated thoughtfully, can lead to superficial learning. For example, reliance on slides without hands-on activities undermines the inquiry-based nature of science (Olagbaju, 2023). Implementation often outpaces capacity, with grand ICT initiatives failing to reach classrooms in meaningful ways. This disconnect leaves teachers and students caught between expectation and reality (Rebecca & Ayodeji, 2023). These gaps demonstrate that

ICT integration is not automatically beneficial; its effectiveness depends on alignment with pedagogy, equity measures, and sustainable infrastructure.

Theoretical Underpinning

The strength of any research lies not only in its findings but also in the theoretical scaffolding that frames the inquiry. For this research, two complementary theories—Digital Divide Theory and Diffusion of Innovations Theory—were adopted to make sense of how socio-economic conditions, infrastructure, and institutional practices shape the integration of ICT in Nigerian science education. These frameworks help us to interpret not just what is happening in schools, but why such patterns exist and how they might evolve. The concept of the digital divide refers to inequalities in access to, use of, and ability to benefit from digital technologies (Ragnedda, 2020). Initially, the digital divide was understood narrowly as the gap between those who own computers or internet connections and those who do not. However, later scholarship expanded the notion to include differences in digital skills, quality of access, and the ways technologies are used (Allmann & Blank, 2021). In the Nigerian context, the digital divide is vividly visible in the education sector. While elite private schools in cities like Lagos, Abuja, and Port Harcourt invest in smart classrooms, interactive whiteboards, and e-learning platforms, many public schools in rural communities lack even basic electricity (Oshowole, 2024). This structural inequality shapes how students experience science education: some are exposed to virtual simulations of chemical reactions, while others still rely on chalkboard sketches.

Moreover, the divide is not only infrastructural but also socio-economic. Poverty prevents many families from purchasing laptops, smartphones, or data bundles for their children. This means that even where schools introduce ICT, students' ability to engage outside the classroom is limited (Olokooba et al., 2018). Teachers, too, face digital divides—those who receive formal ICT training or work in better-resourced schools are more likely to integrate digital pedagogy, while others remain confined to traditional methods (Jha et al., 2024). By employing the digital divide theory, this research can highlight how systemic inequalities—not just individual choices—explain why ICT-enhanced science education is more accessible to some learners than others in Nigeria. While the digital divide explains inequalities, the Diffusion of Innovations Theory (Adenubi et al., 2025) sheds light on how new practices—such as ICT integration in teaching—spread within an education system. According to Khan et al. (2020), innovations pass through stages: knowledge, persuasion, decision, implementation, and confirmation. Individuals and institutions adopt at different rates, depending on perceived usefulness, ease of use, available support, and cultural acceptance.

In Nigeria, diffusion is uneven. Some schools and teachers act as innovators—experimenting with mobile apps, virtual labs, and blended learning methods. For example, during the COVID-19 pandemic, several private schools quickly shifted to online platforms such as Google Classroom and Zoom (Noah & Gbemisola, 2020). Others, however, resisted adoption, citing lack of training, inadequate infrastructure, or scepticism about technology's value. Many public schools, particularly in underserved regions, remain late adopters or laggards, constrained by weak institutional support and resource scarcity (Abdulkadir & Dakasku, 2025). This theory also highlights the role of change agents—in Nigeria's case, policymakers, NGOs, and donor agencies who promote ICT integration. However, unless these efforts are sustained and adapted to local realities, adoption often stalls after initial enthusiasm. By using this framework, the research interprets ICT integration not as a uniform process but as a diffusion that varies across contexts, shaped by both structural enablers and human attitudes. Together, these theories provide a robust lens for analysing ICT in Nigerian science education.

Identification of Gaps in Existing Knowledge

Although there is a growing body of research on ICT integration in education, several important gaps remain in the Nigerian context, particularly as they relate to science education. These gaps justify the present research and highlight its potential contribution to scholarship and practice. Much of the existing literature on ICT in education in Nigeria tends to focus broadly on general classroom use, teacher digital literacy, or policy formulation (Imhanyehor, 2021). Far less attention has been directed specifically toward science education, despite its central role in national development. Studies often examine ICT adoption across subjects without disaggregating the particular challenges and opportunities unique to science teaching, such as the need for laboratory simulations, hands-on experimentation, and visualisation of abstract concepts. This paper addresses that oversight by focusing explicitly on science education. Existing research documents Nigeria's ambitious policies on ICT in education, but there is an inadequate analysis of how these policies translate into classroom realities. For example, while national frameworks highlight the importance of digital teaching, studies rarely examine the actual disconnect between government aspirations and the lived experience of teachers and students in science classrooms (Walan, 2020). This paper bridges that gap by analysing how socio-economic barriers hinder the realisation of policy goals. Several Nigerian studies acknowledge infrastructure challenges such as poor electricity and internet access (Ezeudu & Fadeyi, 2024), yet there is limited scholarship unpacking the socio-economic dynamics—poverty levels, urban–rural disparities, and household inequalities—that shape digital access. Where these factors are mentioned, they are often treated as background conditions rather than systematically analysed. This research explicitly foregrounds socio-economic barriers as a central lens for understanding ICT integration in science education. While research often highlights the promise of ICT for improving learning outcomes, less attention is paid to the new gaps that ICT itself may create. For instance, disparities between public and private schools, or between male and female students, are rarely discussed as consequences of uneven digital integration. Similarly, pedagogical gaps—where ICT is used superficially without transforming inquiry-based learning—are often overlooked. This research addresses this blind spot by interrogating not only barriers and integration but also the unintended gaps that emerge from digital transformation.

RESEARCH METHOD

This research employed a qualitative desk-based research design, relying on secondary data sources. The focus was on synthesising and interpreting existing knowledge, reports, and statistics on science education in Nigeria within the digital era. A qualitative approach was considered most appropriate because it allows for in-depth analysis of educational challenges and opportunities, particularly where access to large-scale primary data is constrained. The design also enabled the researcher to explore how different socio-economic conditions, ICT initiatives, and emerging learning gaps are documented in Nigeria. Secondary data were drawn from a wide range of credible sources that directly speak to the Nigerian educational landscape. These included: Peer-reviewed journal articles on ICT and science education in Nigeria; Reports from government agencies such as the Federal Ministry of Education (FME), the National Bureau of Statistics (NBS), and the Universal Basic Education Commission (UBEC); International reports relevant to Nigeria, such as those published by UNESCO, UNICEF, and the World Bank; Grey literature, including policy briefs, evaluation reports of Nigerian ICT-in-education projects, and academic conference papers. Special attention was given to documents discussing Nigeria's National ICT in Education Policy, the Nigeria Education Sector Analysis reports, and national development plans that touch on digital learning. The selection of materials followed these criteria: Contextual relevance – sources had to focus on Nigeria or include Nigeria within comparative African studies. Topical focus – sources needed to address at least one of the research areas: socio-economic barriers, ICT integration, or emerging gaps in science teaching and learning. Credibility – preference was given to peer-reviewed works, official government reports, and publications by recognised international organisations. Timeliness – emphasis was placed on documents from 2012–2025, to reflect Nigeria's ongoing ICT policy implementations and digital reforms. The selected documents were subjected to thematic content analysis. The process involved reading, coding, and categorising information into major themes. Three overarching themes emerged, aligned with the research's objectives: Socio-economic barriers (e.g., poverty, rural–urban disparities, inadequate infrastructure, and electricity challenges); ICT integration (e.g., adoption of e-learning, teacher digital competence, and policy initiatives); Emerging gaps (e.g., persistent digital divide, gender inequities, and inadequate teacher preparation). Each theme was further broken into sub-themes to highlight Nigeria-specific dynamics, such as the impact of erratic power supply on ICT adoption in schools, or the limited availability of functional computer laboratories in rural areas. The reliance on secondary data posed certain limitations. Firstly, access to up-to-date and reliable national data is often constrained by inconsistent reporting practices in Nigeria. Secondly, government statistics and reports may sometimes underrepresent rural realities or fail to capture informal learning contexts. Thirdly, thematic content analysis requires interpretation, and while efforts were made to remain objective, some level of subjectivity is inevitable. Despite these limitations, this approach provides a rich and cost-effective means of examining the state of science education in Nigeria's digital era.

RESULTS AND DISCUSSION

Socio-economic barriers to science education in Nigeria

The thematic review of Nigerian-focused literature, policy documents and national statistics shows that socio-economic barriers act as an interlocking web that constrains meaningful use of ICT for science teaching and learning. Rather than a single problem, the evidence points to a cluster of structural obstacles — unreliable power, uneven internet access, low household income and device affordability, weak school infrastructure (labs and computer rooms), and inequalities by region, gender and poverty status — all of which reduce students' opportunities for inquiry-based, digitally-enriched science learning. A recurring and immediate barrier is electricity — both access and reliability. National statistics and sector reports indicate that barely half of Nigerian households have stable grid connections, and the grid remains fragile with periodic nationwide collapses that interrupt schooling and ICT-enabled activities. The intermittent nature of power supply makes it costly for many schools to sustain computer labs, run demonstrations, or charge devices; when the grid fails, learning scheduled around digital tools collapses with it. This is more than inconvenience: it shapes what teachers are willing to plan for in a lesson and what administrators will invest in for a school.

Nigeria has seen a large rise in mobile and broadband subscriptions, yet high subscription numbers mask wide gaps in meaningful connectivity for schooling. National telecom and statistical data show many active subscriptions, but household and school-level connectivity that supports synchronous virtual lessons or large downloads remains uneven — especially outside major cities. In practice, teachers and students in many rural and peri-urban schools cannot reliably depend on bandwidth-intensive resources such as virtual labs or video experiments. Poverty and income inequality are central to the device gap. A large share of the Nigerian population remains multidimensionally poor, and many families prioritise daily survival needs over purchasing smartphones, tablets or paying for data. This constrains students' out-of-school access to learning platforms and reduces equitable participation in blended or remote science activities. The absence of affordable, durable student devices means that even when teachers attempt ICT-based instruction, a sizeable portion of learners remain excluded.

Multiple reports and media analyses indicate a low prevalence of functional science laboratories and computer facilities in public schools. Where "computer labs" exist, they are often under-resourced, poorly maintained, or lack electricity and internet. This restricts hands-on practical work in science and prevents authentic integration of digital simulations or data-logging tools that would deepen conceptual understanding. The limited computer proficiency reported among senior secondary students also reflects constrained access to meaningful practice. Socio-economic barriers extend beyond physical infrastructure to human capital. Teachers in under-resourced schools face heavy workloads, limited in-service training opportunities, and the personal costs of using their own devices or data to support learners. Many schools lack funded, sustained professional development in ICT pedagogy for science; where training exists, it is often short, technical, and decoupled from science pedagogy. On the student side, poverty-driven opportunity costs — needing to work, travel long distances, or lack quiet research space — further limit engagement with ICT-supported learning outside class.

The socio-economic barriers are neither uniform nor neutral. Northern and rural states, conflict-affected areas, and poorer households show much higher deprivations — both in electricity and school facilities — than metropolitan areas. Gendered patterns in device ownership and internet use also appear in recent studies and briefs: women and girls are less likely to use the internet or own devices, which compounds existing gaps in STEM participation unless interventions are explicitly inclusive. Nigeria's National Policy on ICT in Education sets clear ambitions to mainstream technology in schools and protect learners online, but the reviewed policy documents and implementation reports reveal a gap between policy intent and school-level realities. Resources, financing mechanisms, monitoring and maintenance plans are often inadequate or unevenly distributed, so policy commitments do not automatically translate into functional ICT ecosystems in schools. The evidence therefore suggests that policies and investments that target a single element (e.g., devices) without addressing energy, connectivity, teacher support and poverty-sensitive delivery are likely to deliver uneven results.

ICT Integration in Science Teaching and Learning in Nigeria

The analysis of secondary data reveals that ICT integration in Nigerian science classrooms has moved beyond being a policy aspiration to being a practical necessity, though implementation remains uneven. Evidence shows both positive strides — such as the gradual adoption of e-learning platforms, virtual science experiments, and mobile-based learning tools — and persistent constraints that prevent these tools from achieving their full potential. The integration of ICT in science teaching is shaped by school type, teacher competence, funding priorities, and regional disparities. In many Nigerian urban secondary schools and some tertiary institutions, ICT has been incorporated into teaching through projectors, interactive whiteboards, science simulations, and virtual laboratories. During the COVID-19 pandemic, ICT use expanded further, as teachers experimented with online learning platforms like Google Classroom, Zoom, and WhatsApp groups. In science subjects, digital simulations were especially valuable for demonstrating experiments that were too costly, dangerous, or impractical in under-resourced labs. These efforts show that ICT can enhance visualisation, experimentation, and student engagement in science learning.

The rise of open educational resources (OERs) and government-supported platforms has introduced blended learning approaches in Nigeria. Initiatives such as the Nigerian Research and Education Network (NgREN) and state-level digital education programs (e.g., Lagos Eko Project) have enabled schools to pilot e-learning in science education. Mobile phone-based applications have also been used by teachers to share notes, diagrams, and recorded lessons, bridging some gaps caused by inadequate science labs. However, evidence suggests that uptake is higher in private and urban schools compared to public and rural ones, leading to disparities in exposure. Teacher readiness plays a central role in the effective integration of ICT into science instruction. Findings from secondary sources show that while many Nigerian teachers possess basic computer literacy, fewer have the pedagogical skills to integrate ICT into inquiry-based science lessons. Training programs often emphasise technical skills (e.g., how to operate a computer or use a platform) without embedding these within subject-specific teaching strategies. As a result, ICT is sometimes used superficially — such as presenting PowerPoint slides — rather than transforming how science is taught or fostering critical thinking.

Nigeria has developed policies such as the National ICT in Education Policy and incorporated ICT objectives into national curricula. These frameworks emphasise digital literacy, the provision of ICT facilities in schools, and the integration of ICT in teacher education. However, implementation has been inconsistent. While some states and federal government colleges have introduced ICT-enabled classrooms, many schools — particularly in rural areas — lack the infrastructure to support policy ambitions. This policy–practice gap continues to slow ICT adoption in science classrooms. Despite challenges, ICT integration in Nigerian science education has shown significant promise. ICT tools help students visualise abstract scientific concepts, conduct simulations where real-life experiments are impossible, and access global knowledge resources. For teachers, ICT offers opportunities to collaborate with peers, access teaching resources, and diversify instructional approaches. In contexts where integration has been consistent, studies report improved student motivation, higher retention of scientific knowledge, and better performance in examinations.

While progress is evident, the extent of ICT integration remains hindered by structural and systemic issues. Limited infrastructure (electricity, internet connectivity, and computer labs), lack of sustained teacher training, and inadequate funding are the most frequently cited challenges. Additionally, the heavy reliance on mobile phones for learning — while innovative — often results in superficial engagement with science concepts because small-screen devices are not ideal for complex simulations or detailed diagrams. ICT integration in Nigerian science education is best described as patchy but promising. Where infrastructure and training are available, integration enriches science teaching by making learning interactive, visual, and inquiry-driven. However, without a stronger focus on teacher preparation, equitable access to ICT facilities, and alignment between policy and practice, the benefits will remain concentrated in a few better-resourced schools. For science education to truly thrive in the digital era, ICT integration must move from isolated initiatives to systemic, sustainable adoption across Nigeria's diverse educational contexts.

Emerging Gaps in Teaching and Learning in Nigeria

Although Nigeria has made strides in integrating ICT into education, secondary data reveal a series of emerging gaps that prevent science education from fully benefiting from the digital transition. These gaps are not only technical but also social, pedagogical, and structural, creating new forms of inequality even as ICT opens up opportunities. The findings point to persistent digital divides, issues of equity and inclusion, misalignment between teacher preparation and digital demands, and wider systemic gaps between policy intentions and classroom realities. Despite improvements in broadband penetration and mobile phone ownership, the digital divide remains stark across Nigeria's educational system. Rural communities and low-income households are disproportionately excluded from meaningful ICT use in science classrooms. While students in well-funded urban schools may have access to projectors, digital labs, or e-learning platforms, their peers in rural schools often rely on chalkboards and textbooks as the main instructional tools. This uneven access reproduces existing inequalities, ensuring that digital skills and science literacy become privileges of the few rather than rights of all.

The integration of ICT has highlighted new equity challenges. Girls, students with disabilities, and learners from poorer households face barriers in owning devices, accessing digital resources, and participating fully in technology-based learning. Cultural and socio-economic factors restrict girls' access to mobile phones or internet use in some communities, limiting their participation in digital science programs. Similarly, most ICT initiatives in schools are not designed with accessibility in mind, leaving out students with visual or hearing impairments who require assistive technologies. This exclusion undermines Nigeria's broader goals of inclusive education and equitable participation in STEM fields. Teacher competence is a critical area where gaps persist. Many teachers remain unfamiliar with how to embed ICT into science pedagogy beyond surface-level use. Thematic review of training programs shows that workshops often focus on general ICT literacy but do not equip teachers with subject-specific strategies for integrating digital tools into experiments, problem-solving, or inquiry-based learning. As a result, ICT is sometimes underutilised or used in ways that do not transform student learning experiences. This gap between teacher training and classroom practice reduces the effectiveness of ICT in science education.

Another emerging gap is the tendency to focus on technology for its own sake rather than as a means to enhance scientific inquiry. In some schools, ICT is used mainly to deliver lectures via slides or videos without engaging students in critical thinking, experimentation, or collaborative problem-solving. This risks turning ICT into a passive consumption tool rather than an enabler of active science learning. Without careful pedagogical alignment, ICT may widen the gap between traditional rote learning and the deeper inquiry-based approaches needed in modern science education. Nigeria's education policies, including the National ICT in Education Policy, articulate ambitious goals for ICT adoption. However, the secondary data consistently highlight a gap between these policies and actual school realities. Many policies lack adequate funding, monitoring, and follow-up mechanisms, leaving schools to navigate ICT adoption unevenly. Implementation is often more visible in pilot projects or elite schools than in public secondary schools, particularly in rural or disadvantaged areas. This disconnect creates a gap between the vision of a digitally inclusive science education system and the lived experiences of teachers and students.

The combined effect of these gaps is a risk of widening inequalities in scientific literacy and digital competence. If current trends continue, Nigerian students from privileged schools may emerge well-prepared for the demands of a digital economy and global STEM opportunities, while their peers from marginalised backgrounds may fall further behind. This divergence threatens national development goals and undermines the role of science education as a driver of innovation and equity in Nigeria's knowledge economy. The analysis suggests that Nigeria's journey toward digital science education is at a crossroads. While ICT tools offer immense potential, the emerging gaps indicate that integration alone does not guarantee inclusion or quality. Unless socio-economic, pedagogical, and policy–practice gaps are addressed, ICT adoption may reinforce old inequalities under new forms. The challenge ahead is to ensure that ICT becomes a leveller rather than a divider in Nigerian science classrooms.

Discussion of findings

This research shows that Nigeria's shift to digitally-mediated science education is real but highly uneven. The thematic synthesis identified three tightly linked findings: socio-economic barriers operate as an interlocking web—unreliable electricity, poor internet, household poverty and device unaffordability, weak school laboratories, and regional inequalities—that limit meaningful ICT use in science classrooms; ICT integration is growing (projectors, virtual labs, Google Classroom, mobile tools), but the uptake is patchy and concentrated in urban and private schools, and teacher training is often technical rather than pedagogically oriented; and new gaps are emerging as a product of uneven adoption—persistent digital divides, gendered access issues, superficial use of digital tools that do not support inquiry-based science learning, and a persistent policy–practice gap. These conclusions are grounded in the document's thematic review of policy reports, national statistics, and peer-reviewed studies.

The findings of this research align with a growing body of literature that highlights the uneven and often fragile nature of ICT integration in Nigerian education. Oshowole (2024) and Mohammed and Edu (2021) both emphasise that infrastructural deficits—particularly unreliable electricity and inadequate internet connectivity—remain formidable barriers to the effective use of ICT in classrooms. This is consistent with our findings that socio-economic and infrastructural constraints are the most significant obstacles facing science education in the digital era. Similarly, teacher preparation emerged as a recurring theme in both this research and prior research. Obada et al. (2023) and Isa (2022) reported that most professional development programs focus on generic ICT literacy rather than equipping teachers with subject-specific strategies for integrating technology into science pedagogy. Our results confirm this trend, showing that many science teachers rely on ICT for surface-level tasks such as PowerPoint presentations, which do little to promote inquiry-based learning. In agreement with studies by Olokooba et al. (2018) and Uzuegbunam (2019), this research also found that poverty and household inequalities restrict students' ability to engage meaningfully with ICT. Even when schools provide some digital infrastructure, students' limited access to devices and internet connectivity outside school hours creates significant disparities in learning outcomes. At the same time, this research contributes new insights by focusing specifically on science education, an area that is often subsumed under broader ICT-in-education discussions (Imhanyehor, 2021; Walan, 2020). Unlike general studies, this work shows that the absence of science-specific digital tools—such as virtual laboratories and simulation platforms noted by Potkonjak et al. (2016) and Poultsakis et al. (2021)—directly undermines the potential for ICT to transform science classrooms. Another divergence lies in the way this research conceptualises barriers. While earlier studies by Okudolo and Ojakorotu (2021);

Rebecca and Ayodeji (2023) often discussed infrastructural, pedagogical and equity challenges separately, our findings reveal that these issues interact to create a “compound disadvantage.” For example, even when teachers have been trained, their ability to implement new methods is curtailed by a lack of power or internet access. This systemic framing helps explain why piecemeal interventions—such as providing devices without addressing connectivity or power—have repeatedly fallen short of expectations.

Beyond classroom practice, the findings speak to a broader national and global phenomenon: the risk that digitalisation without equity will reproduce—and even amplify—existing social inequalities. In Nigeria, science education is a strategic lever for economic development and innovation. If digital tools are available only to urban and better-funded schools, the country risks a two-tier system of scientific literacy: a digitally privileged cohort prepared for STEM careers and a larger cohort left behind. That outcome would undercut national development goals, workforce readiness, and commitments to SDG-4 (inclusive quality education). The research has significance not only for school managers and teachers but for planners, telecoms, energy policymakers, and donors who must coordinate to ensure the digital transformation of education is also a socially inclusive one.

Policies must move from high-level targets to realistic, resourced implementation plans that bundle connectivity, power solutions, device access, teacher professional development, and maintenance funding. Teacher development should prioritise subject-specific digital pedagogy for science (how to embed simulations, remote labs, data activities, and inquiry lessons), not only basic ICT literacy. Sustainable power (e.g., solar microgrids), low-cost school connectivity models, and public-private partnerships with telcos can be pivotal. Interventions must be designed to close gender and disability gaps (e.g., subsidised device schemes for girls, assistive technologies, community sensitisation). Investment in longitudinal, outcome-driven research is needed to measure whether ICT interventions actually improve science understanding and participation in STEM pathways. The observed pattern is the product of structural, institutional, and cultural dynamics: Chronic underinvestment in public schooling and infrastructure means many schools lack the baseline resources required for ICT. Ambitious national policies have not been matched with reliable financing, maintenance plans, or decentralised accountability, so pilot projects often remain isolated. Teacher training programs typically emphasise basic ICT skills, and there are few incentives or supports to redesign science pedagogy around digital tools; time pressure and heavy workloads push teachers toward low-effort uses (slides, PDFs), limiting pedagogical transformation.

Recommended actions and directions for future reform

Short-to-medium term (0–3 years)

1. Bundle interventions: design school ICT grants that explicitly require/finance power solutions, internet connectivity, device pools, and a maintenance budget rather than only supplying hardware.

2. Subject-focused PD: roll out sustained teacher-development programs that train science teachers in digital inquiry methods (virtual labs, data collection tools, scaffolded simulations), plus classroom mentoring and communities of practice.
3. Targeted equity measures: launch device-subsidy or loan programs prioritising girls and low-income students; include accessibility checklists for learners with disabilities.
4. Pilot solar + connectivity models: scale carefully evaluated pilots that combine solar power and low-cost, managed connectivity in rural schools.

Medium-to-long term (3–7 years)

1. Curriculum and assessment alignment: revise science curricula and assessments to reward inquiry and digitally-mediated experimentation, which will change teacher incentives and classroom design.
2. Sustainability and maintenance units: mandate school-level maintenance line items in budgets and create regional technical support hubs that service school ICT.
3. Public-private partnerships: create transparent PPP frameworks with telecoms, device manufacturers and EdTech providers that specify service levels, data-affordability commitments, and local capacity transfer.
4. Robust monitoring and research: invest in mixed-method longitudinal studies to assess learning outcomes, gender/disability impacts, and cost-effectiveness of interventions; use results to scale what works.

CONCLUSION

This research has examined the opportunities and challenges of science education in Nigeria within the context of the digital era. While many of the results corroborate earlier research, several important findings distinguish this research from previous works. Unlike most ICT-in-education studies that treat digital adoption as a broad, cross-curricular issue, this research underscores the science-specific gaps in ICT provision. It reveals that the absence of subject-tailored tools—such as simulations, virtual laboratories, and data-logging equipment—directly undermines the pedagogical transformation of science classrooms. Another distinctive finding is the recognition of how infrastructural, economic, and pedagogical barriers operate not in isolation but as an interconnected system. This "compound disadvantage" perspective explains why interventions that target only one barrier, such as distributing devices, often fail to deliver sustainable improvements. The main value of this research lies in its contribution to both concept and practice. Conceptually, it reframes ICT adoption in science education not as a stand-alone technical issue but as part of a socio-economic and pedagogical ecosystem. This integrated view can guide policymakers and educators toward more holistic approaches. Methodologically, the research contributes by synthesising policy documents, existing scholarship, and thematic evidence into a framework that highlights science-specific ICT needs, moving beyond the generalised discussions that dominate current literature. Additionally, the research focused on Nigeria, and while its insights may resonate with other low- and middle-income countries, direct generalisation should be made cautiously. Future research should therefore adopt more empirical and participatory approaches, involving teachers, students, and policymakers directly in data collection to validate and enrich the conceptual framework presented here. In addition, future work should explore the intersections of gender, disability, and socio-economic status with digital access to ensure that proposed solutions foster equity alongside innovation. In conclusion, this research contributes a fresh lens by highlighting the science-specific and systemic nature of ICT challenges in Nigerian education. Its findings call for integrated, equitable, and subject-sensitive strategies that can genuinely transform science learning in the digital era.

REFERENCES

Abdulkadir, A. O., & Dakasku, M. (2025). Transforming Counselling Services Through Artificial Intelligence In Nigerian Schools: Innovations, Challenges And Future Directions. *International Journal of Innovative Psychology & Social Development 13*(2), 52-59

Adenubi, O. A., Samuel, N., & Oyenuga, A. O. (2025). A framework for education technology integration in Nigerian basic school system: Digital framework for technology integration in education (DIFTE) for basic school system. *University of Ibadan Journal of Science and Logics in ICT Research*, *13*(1), 188-199.

Agbovu, D., & Chukwuma, C. M. (2025). Assessment of technological innovations in educational planning and policy implementation in Nigeria. *BW Academic Journal*, *2*, 47-55.

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), 1-37.

Allmann, K., & Blank, G. (2021). Rethinking digital skills in the era of compulsory computing: methods, measurement, policy and theory. *Information, Communication & Society*, *24*(5), 633-648.

Anthony, E. E. (2021). *Comparison of Secondary School Students' Chemistry Performance in WAEC and NECO Examination in Olamaboro Local Government Area, Kogi State* (Bachelor Project, Federal University of Technology, Minna).

Bello, O., & Ajao, A. O. (2024). Digital literacy and skills development in Nigeria: Policies, barriers and recommendations. *Journal of African Innovation and Advanced Studies 5*(2),133-150.

Costa, A. C. F., de Brito Silva, A. M., Espuny, M., Rocha, A. B. T., & de Oliveira, O. J. (2024). Toward quality education: Contributions of EdTech to the achievement of the fourth United Nations Sustainable Development Goal. *Sustainable Development*, *32*(3), 1634-1651.

Emeka, A., Margaret, A. F., Jacob, O. N., & Olatunde-Aiyedun, T. G. (2021). Problems facing science teachers in public secondary schools in Nigeria and way forward. *International Journal of Discoveries and Innovations in Applied Sciences*, *1*(5), 118-129.

Ezeudu, T. S., & Fadeyi, T. J. (2024). Examining the influence of infrastructure deficit on economic activities, education, and healthcare in rural areas of Nigeria. *Nnamdi Azikiwe Journal of Political Science*, *9*(1), 155-176.

Fafunwa, A. B., & Aisiku, J. U. (Eds.). (2022). *Education in Africa: A comparative survey*. Taylor & Francis.

Imhanyehor, G. O. (2021). Digital literacy and primary educational system in Nigeria. *Journal of public administration, finance and law*, *10*(20), 206-221.

Isa, J. O. (2022). *Nigerian Teachers' Perceptions and Experiences of Integrating Literacy Strategies Into Science Instruction* (Doctoral dissertation, Walden University).

Jha, J., Mays, T., Balaji, V., & Scott, P. (2024). Digital Policy for Equity and Openness. *Journal of Open, Distance, and Digital Education*, *1*(1), 1-15.

Jolaoluwa, G. T., Mustapha, A. G., Salami, S. A., & Oluwagbemi, E. R. (2024). Harnessing science education for future transformation in Nigeria. *Educational Perspectives*, *12*(1), 255-267.

Kemi, S. A. (2023). *School principals' implementation of Information and Communication Technology Policy in Lagos State secondary schools, Nigeria* (Doctoral dissertation, University of Pretoria).

Khan, M. T., Khan, T. I., & Khan, S. (2020). Innovation & its diffusion in business: Concept, stages & procedural practices. *sjesr*, *3*(4), 174-186.

Mathew, S., Janet, S., Zik, K., & Isaac, E. A. (2025). Problems Associated with the Migration of Nigerian Tertiary Institutions' Electricity to Band A. *Journal of African Innovation and Advanced Studies 9*(2), 82-94.

Mhlongo, S., Mbatha, K., Ramatsetse, B., & Dlamini, R. (2023). Challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments: An iterative review. *Heliyon*, *9*(6).

Mohammed, M. O. B., & Edu, A. O. (2021). Accessibility of School Children to Remote Learning in Nigeria: Challenges and Way Forward. *Innovation and Technology for Sustainable Educational Development*; *Proceedings of the 6th International Conference of the Faculty of Education, Lagos State University, Nigeria*.

Ndjama, J. D. N. (2025). Bridging the Digital Divide in the Access and Usage of Technology Through Digital Literacy in Rural Vocational Schools. In *Institutes of Higher Education (IHE) and Workforce Collaboration for Digital Literacy* (pp. 91-124). IGI Global Scientific Publishing.

Noah, O., & Gbemisola, K. (2020). Impact of Google Classroom as an online learning delivery during COVID-19 Pandemic: The case of a secondary school in Nigeria. *Journal of Education, Society and Behavioural Science*, *33*(9), 53-61.

Obada, D.O., Bako, R.B., Ahmed, A.S., Anafi, F.O., Eberemu, A.O., Dodoo-Arhin, D., Oyedeji, A.N., Salami, K.A., Samuel, B.O., Samuel, E.T., & Obada, I.B. (2023). Teaching bioengineering using a blended online teaching and learning strategy: a new pedagogy for adapting classrooms in developing countries. *Education and Information Technologies 28*(4), 4649-4672.

Okonkwo, O. S. (2024). Evaluating Nigeria's National Planning for Sustainable Development Goals. *Journal of Sustainable Equity and Social Research*, *1*(1), 39-48.

Okpara, G. C., & Ezeador, C. N. (2024). Philosophy of Teaching: Exploring Various Teaching Methods For Improved Education In Nigeria. *Nnadiebube Journal of Philosophy*, *7*(3).

Okudolo, I. P. T., & Ojakorotu, V. (2021). Digitalisation of local governance for fostering accelerated attainment of the SDGs: Challenges and prospects from a Nigerian perspective. *African Journal of Development Studies*, *2021*(si2), 177.

Olagbaju, A. B. (2023). *Teacher-Pupil Project Collaboration, Hands-On Activities and Pupils' Learning Outcomes in Basic Science in the Ibadan Metropolis* (Doctoral dissertation, University of Ibadan, Nigeria).

Olofin, S. O., Ogunjobi, A. O., Falemu, F. A., Akinwumi, I. O., & Olumilua, B. (2023). Science education as a tool for achieving socio-economic development in Nigeria. *International Journal of Development and Economic Sustainability*, *11*(4), 33-44.

Olokooba, I. N., Okunloye, R. W., Abdulsalam, A. A., & Balogun, I. N. (2018). Teachers' Perceived Challenges of Using ICT in Teaching Secondary School Social Science Subjects in Ilorin, Nigeria. *NIU Journal of Humanities 2*(2), 157-166.

Oshowole, S. A. (2024). *Barriers Impacting the Integration of Classroom Technology in Primary Schools in Lagos, Nigeria* (Doctoral dissertation, Saint Leo University).

Oyekanmi, O. O. (2016). *Effects of mentoring and field study instructional strategies on students' learning outcomes in climate change concepts in social studies in Lagos State* (Doctoral dissertation, University of Ibadan, Nigeria).

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*, *95*, 309-327.

Poultsakis, S., Papadakis, S., Kalogiannakis, M., & Psycharis, S. (2021). The management of digital learning objects of natural sciences and digital experiment simulation tools by teachers. *Advances in Mobile Learning Educational Research*, *1*(2), 58-71.

Ragnedda, M. (2020). Traditional digital inequalities: Digital divide. In *Enhancing digital equity: Connecting the digital underclass* (pp. 39-60). Cham: Springer International Publishing.

Rebecca, A. A., & Ayodeji, A. K. (2023). Challenges and Problems in Contemporary Nigerian Society as Rebranding Dynamics for Nigerian Educational System. *International Journal of Contemporary Issues in Education*, *5*(1), 73-82.

Richard, A. (2021). Effectiveness of ICT integration in Nigerian educational system. *Quest journals, Journal of Research in Humanities and Social Science*, *9*, 16-30.

Samarakoon, S., Christiansen, A., & Munro, P. G. (2017). Equitable and quality education for all of Africa? The challenges of using ICT in education. *Perspectives on Global Development and Technology*, *16*(6), 645-665.

Umoh, P. E. U. (2012). *A descriptive analysis of the Nigerian educational framework* (Doctoral dissertation, University of Bridgeport).

Uzuegbunam, C. E. (2019). The digital lifeworlds of young Nigerians–Exploring rural and urban teens' practices with and negotiation of digital technology. Doctoral Thesis, University of Cape Town

Walan, S. (2020). Embracing digital technology in science classrooms—secondary school teachers' enacted teaching and reflections on practice. *Journal of Science Education and Technology*, *29*(3), 431-441.