

LEVERAGING INTERNET OF THINGS IN 21ST CENTURY EDUCATION IN NIGERIA: GAINS, CHALLENGES, AND FUTURE DIRECTION

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Abstract

This paper examined the need to integrate Internet of Things (IoT) technologies into Nigeria's education system to help close digital divides between Nigeria and her advanced counterpart countries. The benefits, opportunities and challenges for integration of IoT were explored through the lenses of constructionism, connectivism and activity models. Possible technical, pedagogical, financial and social barriers that would face large-scale IoT adoption in schools were examined. To overcome these obstacles, the paper also examined the blended strategies including specialized learning hubs, cloud-sourcing models, mentorship networks, and crowd-computing. Collectively, these approaches could empower leveraging IoT for transformative, project-based connected learning through participatory knowledge-building. Potential navigational tactics were reviewed like contextualized training, activity groups for continual connections, and public-private partnerships to share infrastructure costs. The paper concluded that by guiding implementation with established theoretical models while pursuing innovative technical, economic and social strategies tailored to the local context, noting that Nigeria can successfully overcome barriers to leveraging Internet of Things for advancing 21st century teaching and learning outcomes. However, the paper also acknowledged the need for further research. Areas suggested for future exploration included longitudinal case studies evaluating impact of different infrastructure deployment and financing options. Large-scale surveys were proposed to understand evolving teacher perception and ongoing support needs. Finally, comparative analyses with other developing economies' IoT integration pathways and best practices could provide valuable insights for optimizing Nigeria's approach.

Keywords: Internet of Things; Educational Technology Integration, Technology Adoption Barriers; 21st Century Educational Skills

Introduction

Nigerian education has faced stagnation compared to global standards (Adewole, 2020). Student-teacher ratios average 1:50, is far higher than the recommended 1:25 (Emmanuel, 2014). National learning assessments show majority of students cannot comprehend basic texts or do division, indicating poor learning outcomes (Stephania, Ahmed, & Jacob, 2022). Infrastructure is lacking, with over 72,000 classrooms needed to meet UN standards and only 50% of schools having basic water and sanitation facilities (Alexander et al., 2016). Teaching methods also rely heavily on rote learning rather than critical thinking (West, 2023). However, this stagnation can be reversed if Nigeria could join her advanced counterparts in embracing 21st century technologies. As technologies advance, the ability to incorporate it into various aspects of life has become more feasible. Education is one sector that could see significant transformation through technological advancement especially with Internet of Things.

The IoT refers to the network of physical devices embedded with electronics, software, sensors and network connectivity that enables data collection and exchange over the internet (Onayinka, 2011; Muhammad et.al, 2022). By integrating IoT applications into Nigeria's education system, stagnant classrooms can be transformed through tools that facilitate student-centered active learning, personalized e-learning, remote access from underserved areas, data-driven optimization of administrative functions and infrastructure, and continuous refinement of curricula to accordingly meet the needs of the digital age.

The gains of integrating Internet of Things into Nigeria's education system have not been widely publicized through research, limiting its ability to draw the attention of key decision-makers and stakeholders. While preliminary initiatives show promise, little is known about the tangible benefits Internet of Things can deliver at scale across learning outcomes, access, efficiency and socioeconomic impact. This means that adopting Internet of Things in Nigerian education requires creating widespread understanding of its benefits to garner support from policy makers and all stakeholders (students, staff, schools and communities). A research exposing the demonstrable strides of Internet of Things in areas like active pedagogy, remote learning extension, data-driven operations and maintenance is, therefore, needed to stimulate political motivation and interest in resource allocation for large-scale implementation of Internet of Things in Nigeria education system. To the best of the researcher's knowledge, there is a paucity of research on the task of publicizing IoT's transformational roles in 21st century education system. While no prior research has created awareness of the roles of IoT in improving Nigerian education system, the present study will do more than just publicize benefits, it will also expose challenges faced on-field and provide actionable strategies going forward.

Literature Review

Nature of internet of things

The paradigm of the IoT encompasses networks of physical objects embedded with electronically-enabled sensors, software, and connectivity which facilitate said objects' collection and exchange of data with minimal human intervention (Lopez Research, 2017). IoT enables devices to monitor environmental conditions and communicate with intelligent systems wirelessly (Dhillon, Kalra, Bhagat, & Chandhoke, 2017). It relies upon pervasive sensors that discreetly observe metrics including temperature, motion, and pollution levels (Whitmore, Agarwal, & Xu, 2015). These sensors transmit wirelessly using protocols such as WiFi, Bluetooth, Zigbee, or low power wide area networks to interface with software platforms (Borgia, 2014). Such platforms

assimilate information across disparate endpoints to discern patterns and trigger outcomes via network gateways (Lin et al., 2017).

Common IoT devices include smart appliances, wearable technologies, environmental monitors, industrial machinery, and transportation assets equipped with internet connectivity via onboard integrated circuits (Khan, Khan, Zaheer, & Khan, 2012). Identification techniques like the full meanings of the codes mentioned are as follows: Radio Frequency Identification (RFID), Quick Response codes (QR) codes, Near Field Communication (NFC) tagging digitally distinguish objects (Zhang, Liu, & Lou, 2011).

Central to IoT is data processing using infrastructure such as cloud servers and edge computing clusters which analyze real-time flows of information from billions of interconnected devices (Atzori, Iera, & Morabito, 2010). This analysis enables responsive automated decision-making with applicability in domains including infrastructure management, agriculture, and healthcare through optimization using insights derived (Petrik & Herget, 2019). Artificial intelligence and machine learning techniques further leverage such insights (Samaniego & Detweiler, 2020).

Thus, IoT facilitates ubiquitous sensing and activation capabilities worldwide through perpetual machine interactions and convergence of the physical and digital realm (Okunade & Onayinka, Ajijola, 2015) for purposes like remote monitoring, precision process control, and predictive maintenance (Jia, Karagiannis, & He, 2016).

However, questions arise around the pedagogical merits of such an approach as well as challenges that may undermine its effectiveness.

Potentials of Internet of Things (IoT)

Promotes engagement: IoT enhances engagement through gamification and interactive activities by allowing teachers to incorporate more immersive elements into lessons (Armier, Shepherd, & Skrabut, 2016; Kumar, Tiwari, & Zymbler, 2019). It enables adding activities like games that help stimulate students' interest and involvement. Specific examples include interactive games and quizzes where learners can use connected devices to participate in educational competitions with real-time scoring and feedback (Licorish, Owen, Daniel, & George, 2018). Additionally, IoT facilitates simulations through applications of augmented and virtual reality that provide hands-on, experiential learning opportunities outside traditional classrooms (Hu-Au, & Lee, 2018). Students can explore immersive historical reconstructions or scientific visualizations through these technologies (Serrano-Ausejo, & Mårell-Olsson, 2023). IoT also promotes collaboration using networked tools that allow peers to jointly build virtual objects (Onayinka et al., 2018) or tackle real-world problems together (Dillenbourg, 1999). A further engagement feature is IoT's capacity to collect student performance data to design contextual adaptive scaffolds, providing Just-in-time clues, tasks or feedback tailored to each learner's skills and challenges (Abiodun, James, & Merja, 2022).

Personalized learning: IoT enables personalized learning through collecting student data (Spyrou et al., 2018; Li, 2023). It can tailor lessons based on individual skills like self-paced assignments with difficulty adjusted in real-time (Duong, Bui, & Lu, 2022). Preferences are also accounted for, like allowing musical lessons geared towards favorite genres (Rentfrow, Goldberg, & Levitin, 2011). Assessing prior knowledge helps determine starting points such as skipping basics in well-granted topics. Tracking engagement and struggles aids delivering relevant remedial/extension content (National Research Council, 2002). Lessons can be optimized for diverse skills like pairing

audio instructions with texts for varied learner styles (Singh, 2018). Monitoring comprehension on-the-go further ensures challenges match evolving abilities.

IoT facilitates collaborative learning through new models enabled by connected devices (Kailash, & Abdulaziz, 2022; Satu, Roy, Sunny, & Whaiduzzaman, 2018). Group projects can involve jointly building virtual objects through networked robotic kits (Kumar, Rus, & Sukhatme, 2008). Peers can team up on augmented reality scavenger hunts across devices revealing layers of locations (Lu, Chao, & Parker, 2015). Discussion boards let classmates converse online in real-time on assignments from remote areas (Vargas-Madriz, 2018). Peer feedback is simplified through shared document annotation (Rufai, 2023) or digital portfolio reviews (Nilson, & Goodson, 2018). Experts can live-stream instruction to distributed students participating through interactive polls, comments and breakouts (Cavinato, Hunter, Ott, 2021). Connected devices open gamified labs where small teams solve collaborative coding, wiring or simulation puzzles (Jovanović, & Milosavljević, 2022).

Ubiquitous: Access to education anywhere and anytime is a promising benefit of IoT. With internet connectivity via devices like smartphones, learners can access educational resources remotely (Sprecher, 2023). For example, connected e-books allow students to check out digital textbooks using a library app and study any time outside the classroom (Doering, Pereira, & Kuechler, 2012). Interactive video lessons can also be streamed to devices, enabling self-paced learning on commutes or downtime (Papadopoulou & Palaigeorgiou, 2016). Teachers may give assignments connecting to simulated labs or fieldwork through virtual or augmented reality apps (Minocha, Tudor, & Tilling, 2017). Flipped classroom models are another application, where learners watch pre-recorded lectures at home and use class time for discussion (Iacopo, 2020). This flexible approach benefits rural students or those juggling work/family duties.

Just-in-time supplemental learning through IoT can reinforce formal classroom instruction. For example, IoT devices allow delivering micro-learning lessons (Díaz, Caeiro, López, Escobar, & Vilas, 2021) to students on the fly, such as by publishing short audio or video clips that explain a concept a student is currently researching (Kosterelioglu, 2016). Educators can also create contextual information streams programmed to each student's schedule using connected devices and calendars. For instance, review materials related to an upcoming exam delivered via smart speakers the evening before (Franco et al., 2023). Adaptive practice quizzes accessible through apps help students evaluate and strengthen weak areas in real-time as well (Areed, Amasha, & Abougalala, 2021). Further, interactive activities with IoT-connected objects provide just-in-time experiences. A biology student examining plant samples outdoors could trigger audio explanations through barcodes (Daily, et al., 2016). Such contextual supplementation leveraging constant IoT connectivity motivates lifelong learning beyond classroom walls.

Potential Challenges of Integrating IoT in 21st Century Education in Nigeria

While it is desirable to integrate IOT into the Nigerian educational systems, this review identifies some potential challenges that may affect the integration into the Nigerian educational system. Some of the challenges include:

Technical challenges: Integrating IoT technologies on a wide scale in educational institutions may pose some significant technical challenges (Damilare, Ariyo, & Oke, 2022). The existing IT systems in most Nigerian schools would require extensive upgrades like network cabling, bandwidth expansion and device standardization to support new IoT applications and the influx of

connected devices (Damilare, Ariyo, & Oke, 2022). Additionally, aspects like intermittent power supply, and lack of technical skills among users could potentially hamper scale-up efforts if not properly addressed at the implementation planning stages through strategic partnerships and innovative engineering solutions customized for the local context. More so, reliability issues including devices crashing or networks failing can disrupt lessons, reducing continuity of learning (Tobi, Osman, Bakar, & Othman, 2021). With diverse operating systems and platforms across schools, content interoperability becomes difficult (Jakimoski, 2016). Without common standards for interconnectivity, lessons risk incompatibility (Egyedi, 2007). In remote/under-resourced areas, unreliable networks may impede access (Ishii, 2009). Examples include unreliable electricity supplies crashing routers in certain regions (Mesbahi, Rahmani, & Hosseinzadeh, 2018). Additionally, unforeseen failures like cyber-attacks disrupting networks damage the student experience (Perwej, Abbas, Dixit, Akhtar, & Jaiswal, 2021). Due to these issues, full reliance on technology for education introduces dependencies which when impaired undermine the pedagogical aims of accessibility and engagement IoT planned to facilitate.

Financial challenges: Significant financial outlays are required to deploy IoT for education (Webbylab, 2023). Schools must fund costly equipment purchases to outfit classrooms with networked devices and connectivity solutions initially (Machin, McNally, & Silva, 2007). Once procured, resources are needed to continually replace aging components and upgrade technologies over the systems' lifespan (Ahuff, 2022). In remote or lower income communities, making IoT access universal poses particularly steep barriers without subsidies to distribute affordable devices to every student (Moore, & Vitale, 2019). Such expenses risk hindering comprehensive integration if not addressed.

Pedagogical challenges: Significant pedagogical challenges arise when adopting IoT for learning. Assessment methods require redesign to authentically evaluate interactive, self-paced instruction (Koehler, Mishra, & Yahya, 2007). Educators lack skills to competently operate new technologies without intensive training (Studeo, 2022). Overly relying on devices risks reducing social skills if not balanced with other activities (Kolhar, Kazi, & Alameen, 2021). Teachers face pressures from constantly troubleshooting technical issues disrupting lessons (Habibu, Mamun, & Clement, 2012). For instance, designing assessments for an adaptive IoT-enabled science curriculum requires reinventing current practices. Similarly, without special preparation through courses, many educators struggle integrating a sudden move to IoT classrooms.

Social challenges: Integrating IoT technologies into education presents various social challenges that must be addressed. Student data privacy is a key concern, as personal information collected through IoT devices and platforms could potentially be at risk if not properly secured (Gogus, & Saygin, 2019). Additionally, a digital divide may emerge where less privileged groups lacking reliable internet connectivity or adequate devices become marginalized (Sanders, & Scanlon, 2021). Ensuring appropriate oversight and accountability over student online activities and monitoring learning progress can also be difficult (UNESCO, 2023). These equity issues are further compounded for disadvantaged populations who may find equipping all learners with the necessary IoT resources prohibitive due to financial constraints (Madni et al., 2022). If precautions are not taken to empower vulnerable stakeholders and gain broad consent, such equity and privacy threats have the capacity to undermine IoT's benefits for education. Addressing challenges spanning technical, social, financial and pedagogical spheres will be important for navigating large-scale, sustainable IoT integration in Nigerian education.

Mitigation of the Challenges

This review considered the need to take actions that will provide a pathway to overcoming the challenges. The mitigation suggestions are as follows:

The Home-Grown Factors

Though the review recognizes the technical steps that could be taken to mitigate the challenges, there is need to address the home-grown factors that may affect the full functionalities of the technical solutions when available. The identified home grown factors include finding solutions to Quality of Service, Quality of Experience, government will and policies, infrastructure deficits security issues, and issue of users' privacy (Kunle et al., 2017).

Open standards and protocols: Adopting open standards and protocols would allow for diverse IoT devices and platforms to connect and communicate seamlessly without compatibility issues disrupting the learning process (Noura, Atiquzzaman, & Gaedke, 2018). This enhances reliability and enables numerous learning opportunities. For example, students could collectively monitor environmental factors across a school garden using an assortment of Bluetooth-enabled soil sensors (Carrión, Huerta, & Barzallo, 2018) and micro-climate data loggers (Whiteman, Hubbe, & Shaw, 2000) from different manufacturers. The sensors would transfer real-time readings to a learning management system (LMS) (Mershad, & Wakim, 2018) through an open-source protocol allowing easy integration (Schindelin et al., 2012). Learners could then analyze trends visible through an open application programming interface (API) (Zepecki, Guendelman, DeNero, & Prata, 2020) gaining understanding of ecosystems (Chapin, 2011). Similarly, a science class collaborating on an international water quality study may contribute findings on pH, temperature and dissolved oxygen captured through a variety of Bluetooth or Wi-Fi enabled probes (Bogdan et al., 2023) from multiple sources (Zainurin et al., 2022). An open IoT framework ensures the diverse tools seamlessly synchronize streaming data for the joined investigation regardless of brand (Balakrishna, Thirumaran, & Solanki, 2018). These illustrate how openness raises pedagogical opportunities by allowing educators and students flexibility in their integrated technology selections unrestricted by proprietary constraints.

Technical strategies: Technical issues can be addressed through open-source solutions, robust infrastructure, standardized specifications and modular design (Jroberts, 2023; Bonvoisin, Molloy, Hauer, & Wenzel, 2020). Adopting open-source platforms allows devices and software from different providers to seamlessly connect through common protocols (Nagy, Yassin, & Bhattacharjee, 2010). This requires upfront investment but ensures reliability (Xing, 2020). For example, an open hardware specification for IoT devices in schools allows different sensor brands to integrate on a shared network. Standardizing physical attributes like wireless specifications or software APIs supports interoperability when students bring their own devices (Pal et al., 2018). Modular programming approaches also improve scalability, for example developing lesson apps independently of the connected devices used (Sun, Sun, & Wang, 2012).

Pedagogical strategies: Pedagogical challenges can be mitigated through piloting, support systems, stakeholder collaboration and evaluation (Samaniego et al., 2015; Chanimbe, 2019). Starting small with new technologies allows refining approaches before widespread adoption (Straub, 2009). For example, a new IoT platform for science lessons was first tested in one classroom. Providing dedicated training and technical support for educators can help address any issues with educational technology, allowing them to focus primarily on teaching quality

(Osamwonyi, 2016). Initiatives like regular hands-on workshops and dedicated desks officers can help in ensuring that instructors are adequately equipped to utilize new tools and platforms effectively in their classrooms (Osamwonyi, 2016). When instructional staff have timely access to assistance with troubleshooting problems, it can prevent technical difficulties from disrupting the learning environment. This emphasis on training and support consequently helps technology enhance rather than hamper lesson delivery and student outcomes. Furthermore, regular review of innovations ensures adaptations would address the emerging educational needs (Onayinka, (2011); Lyng, 2021). Collaboration between educational technology developers, schools, and researchers is important to ensure solutions are well-grounded in real-world educational needs (Resta, & Laferrière, 2007). When these stakeholders work together, technologies can be designed and tested in live classroom environments to validate learner and pedagogical fit before widespread adoption. Feedback from end users also helps developers continuously refine products to better serve evolving purposes. This cooperative approach can help in advancing innovations that are meaningfully integrated into learning environments from the start

Policy and economic strategies: The challenges of IoT integration can also be mitigated thorough planning and strategic policy and economic strategies (Onayinka et al., 2022). For example, developing privacy/ethics planning, guidelines, inclusion strategies and financing models can address policy concerns regarding data usage and security (Hayes, & Bulat, 2017). Inclusion strategies that leverage public-private partnerships and phased implementation can expand access into a financially sustainable manner. Establishing alternative financing models like infrastructure sharing or funding from universal service funds can also reduce upfront investment burdens. Well-communicated responsibilities and rights help gain involvement from stakeholders (People Management, 2023). By transparently establishing what is required and entitled for each stakeholder, it creates mutual understanding and accountability. This helps different parties willingly and actively contribute as needed, rather than feeling unclear or removed from decision-making. Good communication of responsibilities and rights is therefore important for fully engaging stakeholders in complex educational technology undertakings.

Another economic strategy is cloud-sourcing to maintain access for underprivileged communities. Leveraging cloud-based platforms can mitigate infrastructural barriers to education technology integration. Hosting digital curricula, administrative systems and student assessments within centralized cloud environments takes advantage of reliable, scalable data centers (Ogwo, Ibegbulem, & Ezema, 2022). This redistributes costs across a wider user base while reducing upfront capital expenditures for local hardware/IT maintenance (Akpoghome, & Nwano, 2019; Dabbagh, & Kitsantas, 2012; Ogwo, Ibegbulem, & Ezema, 2022). When outages occur, cloud-sourcing also maintains continuity since content/services reside off-premises. Overall, as an affordable, resilient solution it can help expand access for underserved groups by optimizing investments. Taking proactive measures to thoughtfully address issues like these through cooperative frameworks and enabling policies can pave the way for more widespread adoption of IoT solutions while circumventing common economic barriers faced during technology integration initiatives in education.

Models Anchoring the Review

Models play a vital role in guiding position papers like one exploring IoT integration in Nigerian education sector. They provide useful frameworks that help define important parameters in an organized, analytical manner. This leads to robust, evidence-based conclusions and policy recommendations regarding strategies needed to support innovative learning initiatives.

Ultimately, such frameworks strengthen the position paper's ability to contribute meaningful insights on technologies revolutionizing 21st century education. This discourse is anchored on: Connectivism Model by George Siemens in 2004; the Constructionism Model by Seymour Papert in 1991; and the Activity Model by Yrjö Engeström in 1987.

Connectivism Model: According to this model, learning occurs through network connections between sources/nodes of information. Key tenets include learning as a connectivity within networks, learner as node, curriculum as connections. In a connectivist model employing IoT, students' research pathways could be recommended through an adaptive learning platform analyzing their online interactions. For example, the platform may suggest additional sources to explore based on keyword similarities between articles already read. Remotely accessed smart devices could also aggregate students' individual note-taking into a shared knowledge bank for the class to reference.

Constructionism Model: Hands-on building of personally meaningful artifacts facilitates creative, engaged learning (An, Sung, & Yoon, 2022). The key tenets include learning through making, using technology to design and experiment. Using IoT, educators could design constructionist assignments where students collaborate virtually on an interactive science simulation. With connected tools, students might remotely operate and record observations from a robotic microscope exploring real specimens. The gaming elements of these models can motivate persistence to finish multi-step projects.

Activity Theory Model: Learning emerges through goal-oriented interactions within a cultural and historical system (Kabuye, & Marjorie, 2019). Key tenets include historicity of activity, mediation of tools and signs, community context. In an activity theory-based IoT environment, classes discuss a community issue like traffic safety through a social network. Students access connected traffic sensors and model proposals for change. Interacting with IoT data makes the learning more situated and authentically tied to solving a real problem.

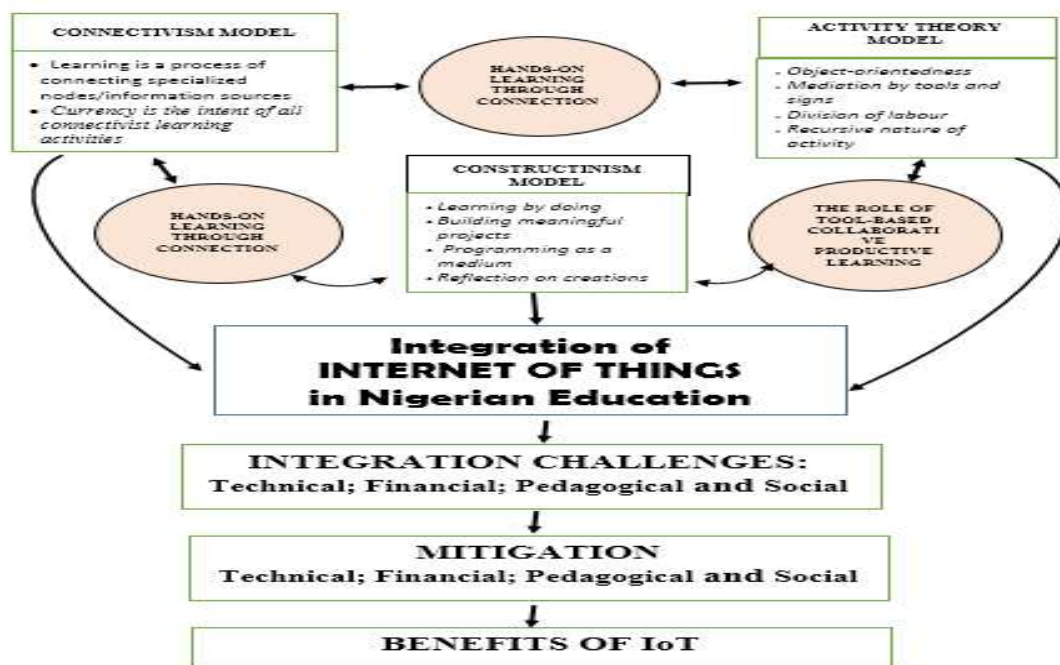


Figure 1: Conceptual Framework of Integration of Internet of Things in Education

This conceptual framework diagram provides a systematic representation of how three important learning theories (connectivism, constructionism, and activity theory) collectively inform the analytical approach to studying IoT integration in Nigerian education. By visualizing each socio-constructivist perspective as a distinct yet related lens influencing the central topic, the diagram illustrates the key concepts, variables, processes and impacts defined by each theoretical perspective. It also demonstrates how practical examples concretize abstract ideas within the theories. Ultimately, the framework structures a well-rounded exploration of both opportunities and challenges for adopting networked technologies to transform pedagogical practices, knowledge development patterns, and overall optimization of the education system based on validated theoretical underpinnings that holistically support such investigation.

Conclusion

This review reveals the long-standing challenges confronting the Nigerian education space and the transformative capacity the Internet of Things brings to bear in solving the identified challenges. The review underscores the urgent need for innovative solutions to combat stagnation and improve learning outcomes in Nigerian schools, as evidenced by the inadequate infrastructure, outdated teaching methods, and poor student performance highlighted in the literature.

By leveraging IoT technologies, such as smart devices, sensors, and data analytics, Nigeria has the opportunity to revolutionize its education system and provide more engaging, personalized, and accessible learning experiences for students across the country. The review outlines several potential benefits of integrating IoT into education, including enhanced student engagement, personalized learning experiences, and ubiquitous access to educational resources.

However, the review also acknowledges the significant challenges that must be addressed to realize the full potential of IoT in Nigerian education. Technical, financial, pedagogical, and social barriers present formidable obstacles that require careful planning, strategic partnerships, and innovative solutions. Mitigation strategies, such as adopting open standards and protocols, providing technical support and training for educators, and implementing inclusive policies, are essential for overcoming these challenges and ensuring equitable access to IoT-enabled education.

Recommendations on Future Research Direction

More work is needed to understand how best to meet the needs of all learners through IoT education models. For example, additional considerations are required regarding students with disabilities or special learning needs to promote full inclusion and accessibility. Qualitative research gathering input from students and support organizations could provide useful insights.

Second, the study did not provide enough depth around sustainable financing approaches for large-scale IoT integration. Beyond public-private partnerships, alternative models may exist but require further exploration. Options such as crowdfunding campaigns or philanthropic funding sourced from impact investors could potentially lower adoption barriers and warrant investigative case studies.

Third, although privacy and security concerns were acknowledged, students' and guardians' perceptions were not qualitatively examined. Gathering lived experiences through interviews and focus groups would allow their priorities and trade-offs to guide policy approaches tailored for meaningful consent and oversight.

Fourth, access solutions for remote communities were vaguely proposed without defining context-specific barriers rural schools may face. Future work could use a community-based participatory research design to co-create locally relevant interventions taking into account things like infrastructure deficiencies or socioeconomic factors.

Fifth, co-designing curricula directly with educators was not described but would aid understanding technical assistance needs and skills development supports to ease integration challenges. Shadowing programs documenting teacher viewpoints could capture on-the-ground realities informing more practical resources.

Finally, long-term randomized control trials are needed to show durability of learning impacts and cost savings over multiple years through longitudinal comparative analyses of diverse IoT models deployed at scale in partnership with regional education boards.

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