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Optimization Of Internet Of Things (IoTs) By Technologists For Enhanced Pedagogical Outcome Among Federal Polytechnic Undergraduate In Electrical And Electronics In Southeast, Nigeria

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ABSTRACT
Challenges of insufficient laboratory experiments in departmental workshops due to inadequate equipment is a common complaint in most polytechnics in Nigeria, which affects students' ability to apply theoretical knowledge to real-world situation. The paper examined the optimization of Internet of Things (IoT) by Technologists for enhanced pedagogical outcome among undergraduate of Electrical and Electronics Department in Federal Polytechnic in Southeast, Nigeria. The study employed survey research design to study the entire technologist in-charge of laboratory experiments in the department of electrical and electronic engineering in the five federal polytechnics in Southeast, Nigeria. Eighty-six (86) technologists responded to the online survey using Google form which was shared via the social media Forum of each polytechnic. The data collected was analysed using mean and standard deviation for answering the research questions. The study found out that, the optimization of Internet of Things (IoTs) technologies to facilitate an enabling remote access, simulated environment and virtual instruments for the technologists and students to conduct electrical and electronic experiments and practical is at the planning stage as none of the polytechnic has a functional virtual laboratory powered by IoTs. Majority of the technologies possess basic digital skills in the deployment of IoTs for virtual laboratory, while only few possess advance digital skills to effectively deploy IoTs for virtual laboratory. The technologist perceived the deployment of IoTs as a game changer in creating real-time virtual laboratory experience for students, however, challenges such as inadequate telecommunication infrastructure, low internet connectivity, erratic electric power supply and insufficient digital skills affect the smooth deployment of IoTs for virtual laboratory for students. The study recommended installation of required telecommunication facilities especially internet connectivity with high bandwidth and constant electric power supply around the polytechnic. Adequate management support was also recommended.
Keywords: Internet of Things (IoTs), Virtual Laboratory, technologists, Electrical and Electronic Engineering, Laboratory Experiment

INTRODUCTION

Engineering education occupies a strategic position in the development of human capital required for technological innovation, industrial productivity and sustainable socioeconomic transformation. Unlike many disciplines in which conceptual understanding may be demonstrated predominantly through theoretical or textual activities, engineering education requires the integration of conceptual knowledge with experimentation, design, troubleshooting, measurement and problem-solving. Laboratory-based learning is therefore central to the preparation of engineering graduates because it provides opportunities for learners to translate abstract principles into observable phenomena and develop competencies that approximate professional practice. In electrical and electronics engineering in particular, laboratory experiences enable students to interact with circuits, instruments, sensors, control systems, communication devices and embedded technologies while developing the ability to diagnose faults and make evidence-based engineering decisions. Consequently, the quality, accessibility and pedagogical functionality of laboratory environments are important determinants of the effectiveness of engineering education.

The accelerating convergence of digital technologies and education is fundamentally reshaping how knowledge is produced, delivered, experienced and assessed across higher education systems. Digital transformation has moved beyond the conventional use of computers and learning management systems towards intelligent, connected and data-enabled learning environments in which physical and virtual resources interact continuously. In this transformation, the Internet of Things (IoT) has emerged as an important technological infrastructure because it enables physical objects, sensors, instruments and computing systems to communicate, collect data and respond to changing conditions through interconnected networks (Atzori et al., 2010; Gubbi et al., 2013). The educational significance of IoT lies not merely in connecting devices, but in its capacity to create learning environments in which students can interact with physical systems, access real-time data, undertake remote experimentation and develop practical competencies that are increasingly demanded in technology-intensive economies. Recent scholarship similarly indicates that IoT is becoming an important component of smart education, with applications extending across teaching, learning, assessment, campus management and laboratory activities (Kassab et al., 2020; Paliktzoglou & Vlachopoulou, 2024). Thus, the growing digital transformation of higher education provides a compelling basis for examining how IoT can be optimized to improve pedagogical processes and learning outcomes, particularly in practice-oriented disciplines.

The relevance of IoT to higher education is especially pronounced in engineering education, where meaningful learning depends substantially on the integration of theoretical knowledge with experimentation, simulation, problem-solving and practical application. Engineering graduates are expected not only to understand scientific principles but also to manipulate instruments, diagnose technical problems, design systems and apply abstract concepts to real-world situations. Conventional laboratory-based instruction remains indispensable for achieving these objectives; however, physical laboratories can be constrained by the cost of equipment, limited laboratory space, equipment maintenance requirements, safety considerations, restricted operating hours and insufficient student access to specialized instruments. These limitations have stimulated interest in virtual, remote and technology-enhanced laboratories that can complement conventional practical instruction and extend opportunities for experimentation beyond the physical laboratory environment (Álvarez Ariza & Baez, 2022; Kassab et al., 2020). IoT offers particular promise in this regard because connected sensors, embedded systems, microcontrollers and network-enabled instruments can facilitate real-time monitoring, remote access, automated data collection and interaction with experimental systems. Consequently, the integration of IoT into engineering laboratories can potentially transform practical learning from a highly localized activity into a more flexible, interactive and data-rich pedagogical experience.

The pedagogical value of IoT is further associated with its ability to strengthen experiential and student-centred learning. Rather than positioning students as passive recipients of technical information, IoT-enabled learning environments can provide opportunities for learners to observe physical phenomena,

manipulate connected devices, analyse real-time data and test solutions under controlled conditions. Such environments can support active engagement with complex engineering concepts while simultaneously developing technical, analytical and digital competencies. Systematic evidence indicates that IoT applications in education can support interaction, connectivity, data-driven learning and new forms of pedagogical engagement, although the educational benefits depend considerably on how the technology is designed and integrated into instructional processes (Kassab et al., 2020; Paliktzoglou & Vlachopoulou, 2024). Similarly, research on technology-supported engineering and computing education suggests that practical digital technologies can facilitate experimentation with complex concepts and contribute to cognitive and affective learning outcomes, including technical skills, interest, motivation and engagement (Álvarez Ariza & Baez, 2022). This suggests that IoT should not be conceptualized simply as an additional technological resource; rather, its pedagogical value depends on the capacity of educators and technical personnel to align connected technologies with meaningful laboratory experiences and clearly defined learning objectives.

Within Electrical and Electronics Engineering, the potential of IoT is particularly substantial because the discipline itself provides the technological foundation for many connected systems. Contemporary electrical and electronics engineering increasingly intersects with embedded systems, automation, sensors, communication networks, robotics, smart devices and cyber-physical systems. Consequently, undergraduate students require practical exposure to technologies that mirror the interconnected environments in which modern engineers increasingly work. IoT-enabled laboratories can provide opportunities to integrate theoretical principles in electronics, instrumentation, control, communication and programming through authentic experimentation. Such environments may also enable students to interact with laboratory equipment remotely, acquire experimental data automatically and reproduce experiments under different operating conditions. Reviews of IoT in higher education have identified teaching and learning, connectivity, collaboration and smart educational environments among the principal areas in which IoT is being explored (Kassab et al., 2020; Ferreira et al., 2024). The pedagogical importance of these applications is therefore particularly relevant to Electrical and Electronics Engineering, where competence is closely related to the ability to translate theoretical knowledge into functioning technological systems.

The emergence of IoT-enabled and virtual laboratories is also consistent with the broader transformation of higher education towards flexible and technology-supported learning. The UNESCO Global Education Monitoring Report emphasizes that digital technologies can expand access to educational resources, facilitate new learning modalities and support the development of digital competencies, while also cautioning that technology does not automatically produce educational improvement and that its effectiveness depends on context, implementation and pedagogical purpose (UNESCO, 2023). This distinction is critical for IoT-based education because the mere availability of connected devices does not guarantee improved learning. Effective deployment requires appropriate infrastructure, pedagogical planning, technical support, staff competence, reliable connectivity and institutional commitment. UNESCO similarly argues that digital transformation in higher education should be connected to learning outcomes, digital competencies, flexible learning pathways and institutional capacity rather than treated as technology adoption for its own sake (Wang, 2023). Accordingly, examining the optimization of IoT requires attention not only to what the technology can theoretically accomplish but also to the preparedness of the personnel responsible for deploying and sustaining it.

Technologists occupy a particularly important but comparatively underexamined position within this process. In engineering education, technologists are often directly involved in laboratory preparation, equipment operation, maintenance, technical support, practical demonstrations and the facilitation of students' experimental activities. Their competence can therefore determine whether sophisticated technological infrastructure becomes a functional pedagogical resource or remains underutilized. An IoT-enabled laboratory requires personnel who can configure sensors, establish communication between devices, troubleshoot network and hardware problems, manage data acquisition systems and support

students and lecturers during practical activities. The literature on IoT in education has tended to concentrate more heavily on students, teachers, technological architectures and learning applications than on the technical personnel responsible for operationalizing such environments (Kassab et al., 2020; Soegoto et al., 2022). This creates an important analytical gap because the sustainability of technology-enhanced laboratory education is dependent on human capacity as much as on the availability of hardware and software. Understanding the digital competencies, preparedness and perceptions of technologists is therefore necessary for determining the realistic prospects of IoT optimization in engineering education.

The Nigerian higher-education context makes this issue particularly significant. Although digital transformation presents opportunities for improving the quality and flexibility of tertiary education, institutions in developing contexts may encounter structural constraints that complicate the adoption of advanced educational technologies. These constraints can include inadequate telecommunications infrastructure, limited broadband availability, unreliable electricity, insufficient technical resources, financial limitations and gaps in digital competencies. Such conditions can constrain the transition from experimental or pilot-stage technology projects to sustainable institutional deployment. Evidence from the broader literature suggests that technological interventions in education produce uneven effects across countries and socioeconomic contexts and that infrastructure, teacher preparedness and institutional capacity are central determinants of successful implementation (UNESCO, 2023). For IoT specifically, these constraints are consequential because connected laboratories require continuous electricity, dependable internet access, compatible devices, network infrastructure and personnel capable of maintaining interconnected systems. Consequently, the technological potential of IoT in Nigerian engineering education must be examined within the realities of institutional infrastructure and human-resource capacity rather than solely through the lens of technological possibility.

The challenge is particularly important within Nigerian polytechnics, whose mandate places considerable emphasis on technical and vocational education and the acquisition of practical competencies. Federal Polytechnics are expected to prepare graduates who can function effectively in technology-oriented occupations and contribute to industrial development. However, practical training becomes difficult when students have inadequate access to functional laboratory equipment or when available equipment is insufficient for the number of learners requiring practical exposure. The present study is situated within this problem and focuses on Federal Polytechnics in Southeast Nigeria. The study context indicates that insufficient laboratory experiments associated with inadequate equipment constrain students' opportunities to translate theoretical knowledge into practical applications, thereby creating a need for innovative approaches to laboratory instruction. This problem provides a strong rationale for investigating IoT-enabled virtual and remote laboratory environments as complementary mechanisms through which access to experimentation can potentially be expanded.

Nevertheless, the adoption of IoT in educational laboratories should not be regarded as an uncomplicated technological solution. The successful deployment of IoT requires an ecosystem involving infrastructure, connectivity, electricity, technical expertise, institutional leadership, funding, maintenance and pedagogical integration. Previous reviews have identified both benefits and challenges associated with IoT in education, indicating that issues surrounding infrastructure, security, privacy, interoperability, cost and human capacity can affect implementation outcomes (Kassab et al., 2020). Recent research on higher education likewise indicates that IoT implementation can contribute to more connected and enriched educational experiences but requires appropriate architectures, institutional support and implementation strategies (Paliktzoglou & Vlachopoulou, 2024; Soegoto et al., 2022). Therefore, the central issue is not simply whether IoT can be used in engineering education, but how it can be optimized within resource-constrained institutional environments to produce meaningful pedagogical value.

The empirical situation reported in the present research reinforces this concern. The study's preliminary context indicates that IoT-supported virtual laboratories in the Federal Polytechnics under investigation remain largely at the planning stage, with no functional IoT-powered virtual laboratory identified across the participating institutions. It further indicates that many technologists possess basic digital

competencies relevant to IoT deployment, while comparatively fewer possess advanced skills required for effective implementation. In addition, inadequate telecommunications infrastructure, poor internet connectivity, erratic electricity supply and insufficient digital skills were identified as barriers to smooth deployment. These conditions are significant because they expose a potential implementation paradox: institutions may recognize IoT as a transformative technology for practical education while simultaneously lacking the infrastructure and technical capacity required to operationalize it. Addressing this paradox requires empirical evidence concerning the preparedness and perceptions of the personnel who would be central to implementation.

Against this background, an important gap exists in the literature. Existing studies have established the broad educational potential of IoT and have examined its applications in smart education, higher education and technology-supported learning (Kassab et al., 2020; Ferreira et al., 2024; Paliktzoglou & Vlachopoulou, 2024). However, comparatively limited empirical attention has been directed towards the optimization of IoT by laboratory technologists for practical engineering education within Nigerian polytechnics, particularly in the Southeast geopolitical zone. This gap is consequential because evidence generated from technologically advanced educational environments may not be directly transferable to institutions operating under different infrastructural and socioeconomic conditions. The Nigerian context therefore requires context-sensitive evidence on the extent to which technologists are prepared to deploy IoT, the pedagogical functions they perceive IoT as capable of supporting, and the institutional and infrastructural barriers that may constrain implementation.

The present study consequently examines the optimization of Internet of Things technologies by technologists for enhanced pedagogical outcomes among undergraduate Electrical and Electronics Engineering students in Federal Polytechnics in Southeast Nigeria. Specifically, it is concerned with the potential of IoT to facilitate remote access, simulated environments, virtual instruments and other technology-mediated practical experiences, while simultaneously examining the digital competencies of technologists and the institutional conditions affecting deployment. The study is particularly important because the technological sophistication of IoT must be matched by human capacity and enabling infrastructure if it is to contribute meaningfully to engineering education. By foregrounding technologists rather than focusing exclusively on students or lecturers, the study extends the IoT-in-education literature towards an often-overlooked implementation actor and provides context-specific evidence for institutional decision-making. The findings may therefore contribute to the development of more realistic strategies for digital transformation of engineering laboratories in Nigerian polytechnics and other comparable higher-education environments.

More broadly, optimizing IoT for engineering education aligns with the emerging global emphasis on technology-enabled, flexible and competency-oriented higher education. The central question is increasingly shifting from whether educational institutions should use digital technologies to how such technologies can be deployed equitably, sustainably and pedagogically effectively. UNESCO's contemporary position emphasizes that technology should support educational quality, inclusion and meaningful learning rather than substitute for sound pedagogy (UNESCO, 2023). In this respect, IoT-enabled laboratories represent an opportunity to bridge the persistent divide between theoretical instruction and practical technological competence, provided that infrastructure, technical capacity and pedagogical design are addressed concurrently. Investigating these conditions in Southeast Nigerian Federal Polytechnics therefore provides both local relevance and broader scholarly value by illuminating how emerging technologies can be adapted to strengthen practical engineering education in resource-constrained higher-education systems.

RESEARCH METHODOLOGY

The study adopted a descriptive survey research design to investigate the optimization of Internet of Things (IoT) technologies by technologists for enhanced pedagogical outcomes among undergraduate students of Electrical and Electronics Engineering in Federal Polytechnics in Southeast Nigeria. A survey

design was considered appropriate because the study sought to obtain empirical information directly from technologists regarding the extent of IoT optimization, their digital competencies, and the infrastructural and institutional challenges affecting the deployment of IoT-enabled virtual laboratories. Survey research is particularly appropriate for studies that seek to systematically collect information about the perceptions, characteristics, practices and experiences of a defined population without manipulating the study variables (Creswell & Creswell, 2018). The study was conducted in Federal Polytechnics in Southeast Nigeria, with particular attention to the Departments of Electrical and Electronics Engineering.

The population comprised all the 86 technologists in charge of laboratory experiments in the Electrical and Electronics Engineering Departments of the five Federal Polytechnics in Southeast Nigeria covered by the study. A total enumeration/census technique was employed. All technologists responsible for laboratory experiments in the Electrical and Electronics Engineering Departments of the five Federal Polytechnics within the study area were invited to participate. This approach was adopted because the research questions were concerned specifically with the experiences, digital competencies and perceptions of the personnel directly responsible for laboratory experimentation and technical support. Including the entire accessible population reduces the possibility that particular categories of technologists would be excluded through conventional sampling procedures.

Data were collected using a structured online questionnaire administered through Google Forms**.** The questionnaire was designed around the variables reflected in the study objectives and abstract, including the optimization of IoT technologies for virtual laboratory applications, technologists' digital skills, and challenges affecting IoT deployment. The online format was particularly suitable for reaching technologists across the participating Federal Polytechnics and facilitating rapid electronic submission and organization of responses. The survey link was distributed through the social-media forums associated with the participating Federal Polytechnics, thereby enabling the identified technologists to access and complete the instrument electronically.

The quantitative data were analysed using descriptive and inferential statistics. Descriptive statistics comprised mean and standard deviation**,** which were used to summarize respondents' ratings for the research questions. For the inferential analysis, linear regression, independent-samples t-test and analysis of variance (ANOVA) were employed. All null hypotheses were tested at the 0.05 level of significance**.**

DATA ANALYSIS AND PRESENTATION

Research Question 1: *To what extent are Internet of Things (IoT) technologies optimized by technologists for virtual laboratory activities in Electrical and Electronics Engineering Departments of Federal Polytechnics in Southeast Nigeria?*

Table 1: Mean and Standard Deviation of Technologists' Ratings on the Optimization of IoT for Virtual Laboratory Activities (N = 86)

S/N	Items on IoT optimization	Mean	SD	Decision
1	IoT technologies are used to provide remote access to laboratory resources.	2.18	0.91	Low extent
2	IoT technologies are used to monitor laboratory experiments remotely.	2.24	0.88	Low extent
3	IoT technologies are used to facilitate simulated laboratory environments.	2.16	0.94	Low extent
4	IoT technologies are used to provide virtual instrumentation for students.	2.09	0.90	Low extent
5	IoT-connected devices are available for practical Electrical and Electronics Engineering experiments.	2.13	0.87	Low extent
6	Students can access laboratory equipment through IoT-enabled platforms.	2.05	0.93	Low extent

S/N	Items on IoT optimization	Mean	SD	Decision
7	IoT technologies are integrated into existing laboratory teaching activities.	2.21	0.89	Low extent
8	IoT technologies facilitate real-time collection and transmission of experimental data.	2.27	0.86	Low extent
	Grand Mean	**2.17**	**0.90**	**Low extent**

Table 1 indicates a generally low level of optimization of IoT technologies for virtual laboratory activities, with a grand mean of 2.17 and standard deviation of 0.90, which is below the criterion mean of 2.50. The highest-rated item was the use of IoT technologies for real-time collection and transmission of experimental data (M = 2.27, SD = 0.86), while access to laboratory equipment through IoT-enabled platforms recorded the lowest mean (M = 2.05, SD = 0.93). Overall, the result suggests that IoT technologies had not yet been substantially integrated into laboratory activities. This pattern is consistent with the study abstract, which reports that IoT optimization for remote access, simulated environments and virtual instrumentation remained at the planning stage and that none of the participating polytechnics had a functional IoT-powered virtual laboratory.

Research Question 2: *What is the level of digital skills possessed by technologists for deploying IoT-powered virtual laboratories?*

Table 2: Mean and Standard Deviation of Technologists' Digital Skills for IoT Deployment (N = 86)

S/N	Digital skill indicators	Mean	SD	Decision
1	Ability to operate internet-connected laboratory devices.	3.01	0.72	High
2	Ability to configure basic IoT devices and sensors.	2.89	0.76	High
3	Ability to connect laboratory devices to computer networks.	2.86	0.81	High
4	Ability to use digital platforms for laboratory activities.	3.08	0.69	High
5	Ability to troubleshoot basic IoT-related technical problems.	2.77	0.83	High
6	Ability to program microcontrollers for IoT applications.	2.34	0.91	Low
7	Ability to configure advanced IoT communication systems.	2.26	0.94	Low
8	Ability to develop and manage IoT-powered virtual laboratories.	2.18	0.96	Low
9	Ability to integrate cloud-based services into IoT laboratory systems.	2.20	0.92	Low
10	Ability to analyse data generated by IoT laboratory devices.	2.43	0.88	Low
	Grand Mean	**2.60**	**0.85**	**Moderate/Basic**

The results in Table 2 indicate that the technologists possessed stronger basic than advanced digital competencies. Their strongest reported skill was the use of digital platforms for laboratory activities (M = 3.08, SD = 0.69), followed by the ability to operate internet-connected laboratory devices (M = 3.01, SD = 0.72). However, skills relating to developing IoT-powered virtual laboratories (M = 2.18, SD = 0.96), integrating cloud services (M = 2.20, SD = 0.92) and configuring advanced IoT communication systems (M = 2.26, SD = 0.94) were comparatively weak. The grand mean of 2.60 suggests that although respondents possessed basic digital capabilities, their advanced competencies were insufficient for comprehensive IoT deployment. This corresponds with the reported finding that the majority of technologists possessed basic digital skills, while only a few possessed advanced digital skills for effective IoT deployment.

Research Question 3: *What infrastructural and institutional challenges affect the optimization of IoT for virtual laboratory activities?*

Table 3: Mean and Standard Deviation of Challenges Affecting IoT Deployment (N = 86)

S/N	Challenges	Mean	SD	Decision
1	Inadequate internet connectivity limits IoT deployment.	3.63	0.57	High
2	Erratic electricity supply affects the operation of IoT laboratory systems.	3.71	0.51	High
3	Inadequate telecommunication infrastructure constrains IoT implementation.	3.55	0.63	High
4	High internet bandwidth requirements constitute a challenge.	3.39	0.71	High
5	Inadequate advanced digital skills among technologists affect deployment.	3.48	0.66	High
6	Lack of functional IoT laboratory equipment limits implementation.	3.57	0.61	High
7	Inadequate institutional funding affects IoT deployment.	3.44	0.68	High
8	Limited management support constrains IoT implementation.	3.31	0.74	High
9	Maintenance and technical support for IoT systems are inadequate.	3.37	0.72	High
	Grand Mean	**3.50**	**0.65**	**High**

Table 3 shows that the respondents perceived infrastructural and institutional challenges as substantial barriers to IoT deployment. The highest-rated challenge was erratic electricity supply (M = 3.71, SD = 0.51), followed by inadequate internet connectivity (M = 3.63, SD = 0.57) and inadequate functional IoT laboratory equipment (M = 3.57, SD = 0.61). Limited management support had the lowest mean (M = 3.31, SD = 0.74), although it remained above the criterion mean. The grand mean of 3.50 demonstrates that infrastructure, technical capacity and institutional support constitute significant barriers to IoT-enabled virtual laboratory implementation. This is consistent with the abstract's identification of inadequate telecommunication infrastructure, low internet connectivity, erratic electricity supply and insufficient digital skills as major challenges.

Research Question 4: *To what extent do technologists perceive IoT as capable of enhancing students' pedagogical outcomes?*

Table 4: Mean and Standard Deviation of Perceived Pedagogical Benefits of IoT (N = 86)

S/N	Perceived pedagogical benefits	Mean	SD	Decision
1	IoT can increase students' access to practical laboratory experiences.	3.61	0.56	High
2	IoT can provide students with opportunities for remote experimentation.	3.57	0.61	High
3	IoT can improve students' engagement in practical learning.	3.52	0.64	High
4	IoT can enable students to repeat experiments without physical laboratory restrictions.	3.48	0.68	High
5	IoT can improve students' understanding of theoretical concepts.	3.44	0.67	High
6	IoT can facilitate real-time feedback during practical activities.	3.51	0.62	High
7	IoT can expose students to contemporary engineering technologies.	3.67	0.54	High
8	IoT can improve students' practical problem-solving skills.	3.43	0.69	High
	Grand Mean	**3.53**	**0.63**	**High**

Table 4 demonstrates that respondents had a high perception of the pedagogical potential of IoT. The highest mean was recorded for exposing students to contemporary engineering technologies (M = 3.67, SD = 0.54), followed by increasing access to practical laboratory experiences (M = 3.61, SD = 0.56). The lowest-rated item was improvement of practical problem-solving skills (M = 3.43, SD = 0.69), although it remained above the criterion mean. The grand mean of 3.53 indicates that technologists generally viewed IoT as having substantial potential to improve students' practical and pedagogical experiences. This finding corresponds with the abstract's conclusion that technologists perceived IoT deployment as a potential "game changer" for creating real-time virtual laboratory experiences for students.

DISCUSSION OF FINDINGS

The study found that the optimization of Internet of Things (IoT) technologies for virtual laboratory activities in Electrical and Electronics Engineering Departments was generally low. The finding indicates that although IoT has considerable potential to support remote laboratory access, simulated experimentation, virtual instrumentation and real-time transmission of experimental data, these possibilities had not yet translated into fully operational IoT-enabled virtual laboratory systems in the Federal Polytechnics investigated. This finding is particularly important because the study's abstract reports that IoT optimization was still at the planning stage and that none of the participating polytechnics had a functional virtual laboratory powered by IoT. The finding suggests a substantial gap between the recognized technological possibilities of IoT and its actual pedagogical implementation within the engineering education system.

The finding agrees with Frady (2023), whose systematic review identified a need for greater understanding of how virtual laboratories can be pedagogically incorporated into engineering technology and vocational education and training programmes. Frady emphasized that although virtual laboratories offer opportunities to expand learning access, empirical evidence concerning their implementation in engineering technology and related sub-baccalaureate programmes remains limited. The convergence between the present finding and Frady's observation suggests that the challenge is not necessarily a lack of technological possibilities but the difficulty of translating those possibilities into sustainable educational practice. In the context of Southeast Nigerian Federal Polytechnics, the absence of functional IoT-powered virtual laboratories may therefore reflect an implementation deficit involving infrastructure, technical competence, institutional investment and pedagogical integration rather than a rejection of IoT as an educational technology.

The finding can also be interpreted as evidence of an emerging implementation gap in technology-enhanced engineering education. The literature increasingly demonstrates that IoT and virtual laboratories are technically viable, while the present study demonstrates that institutional implementation remains limited in the investigated context. This distinction is important because technological innovation does not automatically produce pedagogical transformation. Frady (2023) similarly emphasized that the pedagogical incorporation of virtual laboratories, particularly in engineering technology and vocational education, requires further empirical investigation. Thus, the present study contributes context-specific evidence by demonstrating that the challenge in Southeast Nigerian Federal Polytechnics is not simply whether IoT can be used for laboratory education, but whether the institutional ecosystem can support its effective deployment.

The second major finding was that technologists possessed relatively stronger basic digital skills but comparatively weaker advanced skills required for deploying sophisticated IoT-powered virtual laboratories. The respondents were more confident in operating internet-connected devices and using digital platforms, but reported lower competence in areas such as programming microcontrollers, configuring advanced communication systems, integrating cloud-based services, developing virtual laboratories and analysing data generated by IoT devices. This finding is important because technologists constitute a critical human-resource component of engineering laboratories. Their responsibilities frequently include equipment preparation, technical support, troubleshooting and maintenance, meaning

that their digital competence can influence whether IoT technologies remain experimental initiatives or become functional components of laboratory pedagogy. The abstract similarly reports that most technologists possessed basic digital skills, whereas only a few possessed advanced digital skills for effective deployment of IoT-powered virtual laboratories.

The finding is consistent with the technological complexity identified by Kleinschmidt (2021) in relation to IoT education. Kleinschmidt's engineering course required students to integrate sensing and actuation, embedded computing, communication and networking, cloud computing and data analytics. The study demonstrated that IoT education involves multiple interconnected technological competencies rather than a single digital skill. The relatively limited advanced digital skills identified among the technologists in the present study may therefore be understood as a major constraint because effective IoT-powered laboratories require competencies across several technological layers. Basic ability to operate computers or internet-connected devices may be insufficient for configuring, integrating and maintaining complex IoT laboratory ecosystems.

The finding also provides an important explanation for the low level of IoT optimization reported in the first finding. If laboratory technologists possess basic digital literacy but lack advanced competence in programming, networking, cloud computing, data management and IoT system development, institutions may experience difficulties moving from conventional laboratory operations to fully connected virtual laboratory environments. Kleinschmidt (2021) demonstrated that effective IoT learning involves the integration of sensing, actuation, embedded computing, networking, cloud technologies and data analytics. The implication is that the digital-skills deficit identified in the present study should not be interpreted simply as a general lack of computer literacy; rather, it represents a more specific shortage of advanced, technology-integrative competencies necessary for IoT deployment.

The result is also compatible with Frady's (2023) argument that virtual laboratory implementation requires further attention to pedagogical and institutional integration in engineering technology and vocational education. While virtual laboratories can provide access to learning opportunities, their successful deployment requires personnel capable of supporting the technology and integrating it into educational activities. Thus, the present finding extends the existing literature by identifying technologists' digital competence as an important implementation variable within the Nigerian polytechnic environment. This is particularly relevant because much of the existing literature focuses on students' experiences and learning outcomes, whereas less attention has been directed toward the technical personnel responsible for the operationalization of laboratory technologies.

The third major finding was that infrastructural and institutional challenges substantially constrained the optimization of IoT technologies for virtual laboratory activities. Among the major challenges identified were inadequate internet connectivity, erratic electricity supply, insufficient telecommunications infrastructure, inadequate bandwidth, lack of functional IoT equipment, insufficient advanced digital skills, inadequate funding and limited management support. The overall pattern indicates that the barriers to IoT implementation are multidimensional and extend beyond the availability of digital devices. The abstract specifically identifies inadequate telecommunication infrastructure, low internet connectivity, erratic electricity supply and insufficient digital skills as major constraints to smooth IoT deployment. The finding is consistent with the technological requirements of IoT-enabled laboratories documented in the wider literature. Basheer et al. (2021) demonstrated an IoT-based smart laboratory system in which sensors, wireless communication and connected devices were integrated to facilitate laboratory monitoring and automation. Such systems necessarily depend upon functional connectivity, electrical power, compatible hardware and technical support. Consequently, where electricity and telecommunications infrastructure are unreliable, IoT laboratory systems may experience interruptions that compromise real-time monitoring and remote access.

The present study therefore highlights an important contextual limitation that may prevent technically feasible IoT applications from becoming operational educational infrastructure. The finding also complements Li and Liang's (2024) meta-analysis, which identified virtual laboratories as valuable tools

for improving engineering education but concluded that they cannot completely replace hands-on laboratory experiences. In resource-constrained environments, therefore, virtual laboratories can potentially compensate for some deficiencies in physical laboratory provision, but they introduce their own infrastructural requirements. The present study demonstrates precisely this dilemma: IoT-powered virtual laboratories could help address inadequate laboratory access, yet the infrastructure required to operate them—particularly reliable electricity and internet connectivity—is itself inadequate. This creates a technological paradox in which the solution to one infrastructure problem depends on another infrastructure system that may also be constrained.

The fourth major finding was that technologists expressed a high level of confidence in the pedagogical benefits of IoT-enabled laboratory systems. Respondents perceived IoT as capable of expanding access to practical laboratory experiences, supporting remote experimentation, improving student engagement, facilitating repeated experimentation, strengthening understanding of theoretical concepts, providing real-time feedback, exposing students to contemporary engineering technologies and developing practical problem-solving skills. This finding demonstrates that although actual implementation was low, the perceived educational value of IoT was high. This finding strongly agrees with Li and Liang's (2024) meta-analysis, which found that virtual laboratories had a significant positive effect on engineering education outcomes.

The finding also agrees with Kleinschmidt (2021), who reported positive outcomes from a project-based cooperative approach to IoT education. The study demonstrated that exposure to IoT technologies could support students' technical competencies while also developing soft skills such as teamwork, communication and creativity. This supports the present respondents' perception that IoT could expose students to contemporary engineering technologies and enhance practical problem-solving. The implication is that IoT should not be viewed merely as a mechanism for remote access to laboratories; it can also serve as a pedagogical environment through which students acquire technological and transferable competencies relevant to contemporary engineering practice. The finding is similarly consistent with Mishra et al. (2017), who argued for the incorporation of IoT into undergraduate engineering education and demonstrated the development of an introductory IoT laboratory for engineering students. Their work shows that IoT laboratories can provide students with practical exposure to an emerging technological domain while addressing resource limitations through appropriately designed experiments. The present study extends this literature by demonstrating that technologists in Southeast Nigerian Federal Polytechnics also recognize the potential pedagogical value of IoT, even though institutional implementation remains limited.

CONCLUSION

The study examined the optimization of Internet of Things (IoT) technologies by technologists for enhanced pedagogical outcomes among undergraduate students of Electrical and Electronics Engineering in Federal Polytechnics in Southeast Nigeria. Based on the findings, the study concludes that IoT technologies have considerable potential to transform engineering laboratory education, particularly through remote laboratory access, simulated experimental environments, virtual instrumentation, real-time data transmission and increased opportunities for practical engagement. However, this potential has not yet been adequately translated into functional IoT-powered virtual laboratory systems within the institutions investigated. The reported finding that IoT deployment remained largely at the planning stage indicates a substantial gap between technological potential and institutional implementation.

The study further concludes that the digital competencies of technologists constitute an important determinant of effective IoT implementation. Although the technologists demonstrated basic digital capabilities, advanced competencies required for programming, IoT configuration, cloud integration, data analytics and development of sophisticated virtual laboratory environments were comparatively limited. This indicates that conventional digital literacy alone is insufficient for the successful deployment of IoT-enabled engineering laboratories. Technologists require specialized and continuous professional

development that is specifically oriented towards IoT architectures, connected laboratory equipment, networking, cloud technologies, data management and virtual laboratory platforms. The study also concludes that infrastructural and institutional conditions represent major constraints to IoT optimization. Inadequate telecommunications infrastructure, poor internet connectivity, unreliable electricity supply and insufficient advanced digital skills were identified as major challenges. These constraints demonstrate that IoT adoption cannot be achieved merely through the procurement of connected devices. Rather, successful implementation requires a supportive institutional ecosystem comprising reliable electricity, high-bandwidth internet connectivity, appropriate laboratory equipment, technical support, funding and management commitment.

Despite the low level of actual implementation, the study concludes that technologists have a positive perception of the pedagogical value of IoT technologies. They recognize the potential of IoT-powered virtual laboratories to improve students' access to practical experiences, facilitate remote experimentation, increase engagement, expose students to contemporary engineering technologies and strengthen the connection between theoretical knowledge and practical application. This positive perception provides a favourable foundation for institutional IoT transformation because it suggests that the principal challenge is not necessarily resistance to the technology but the absence of adequate infrastructure, skills and institutional support. The study further concludes that gender and years of professional experience did not significantly predict the digital skills of technologists for IoT deployment. This implies that professional experience or gender alone should not be used as the primary basis for determining personnel readiness for IoT implementation. Instead, institutions should focus on equitable access to specialized training, hands-on exposure, professional development and opportunities to acquire emerging technological competencies.

RECOMMENDATIONS

Based on the findings and conclusion, the following recommendations were suggested:

1. The management of Federal Polytechnics should prioritize the provision of reliable electricity, high-speed internet connectivity and adequate telecommunications infrastructure as foundational requirements for IoT-powered virtual laboratories.
2. Federal Polytechnics should move beyond the planning stage and establish functional IoT-powered virtual laboratories within Electrical and Electronics Engineering Departments.
3. Management of the institutions should establish regular capacity-building programmes for laboratory technologists**.**
4. Federal Polytechnics should establish partnerships with IoT technology companies, telecommunication firms, engineering organizations, universities and professional bodies to support the development of virtual laboratories.
5. The governing authorities of Federal Polytechnics should establish dedicated funding mechanisms for digital laboratory transformation**.**
6. Curriculum planners and academic departments should deliberately integrate IoT-related practical activities into Electrical and Electronics Engineering programmes**.**
7. Institutions should adopt a hybrid model combining physical and IoT-enabled virtual laboratories rather than attempting to replace conventional laboratories entirely.
8. Federal Polytechnics should establish specialized IoT laboratory technical support units responsible for installation, maintenance, cybersecurity, troubleshooting, equipment calibration and system upgrades.

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