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Designing IoT-based Curriculum for Industrial Education: A Framework for Skill Development in Nigerian TVET

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Abstract

The rise of Industry 4.0 has necessitated transformative shifts in skills acquisition and re-skilling, especially among technical and vocational education trainees, owing to emerging technologies such as the Internet of Things (IoT). This study investigated the impact of IoT-integrated curriculum design on skill acquisition and re-skilling within Nigerian TVET institutions. Anchored on Constructivist Learning Theory and the Technology Acceptance Model (TAM), the research employed the mixed-methods approach using 200 students and 15 trade instructors selected using a stratified random sampling technique from five technical institutions. IoT-based Curriculum Questionnaire-ICQ ($r = 0.87$) was used to obtain information from the students on their perceptions, learning experiences, and outcomes related to IoT-enhanced instruction, while the qualitative component involved semi-structured interviews with trade instructors. The IoT curriculum design was the strongest predictor of student technical competency, followed by infrastructural support as there was a strong positive correlation ($r = 0.76$, $p < 0.01$) between IoT curriculum integration and skill proficiency scores. The study 84% of students agreed that IoT-enhanced projects improved their ability to apply technical concepts in real-world situations, and 78% reported improved digital literacy through hands-on use of IoT dashboards and embedded sensors. The study concluded that curriculum reforms, educator training, and policy alignment will foster digitally resilient learners and bridge the skills gap in African industrial education.

Keywords: Internet of Things (IoT), 4th Industrial Revolution, Technical and Vocational Education (TVET), Sustainable Education reform, Curriculum design

Introduction

Industrial education has long served as the backbone of workforce preparation, especially in emerging economies. However, technological advancement has widened the gap between traditional skill training and modern industrial demands (Okolie, Salami & Adebayo, 2020). IoT, defined as a system of interrelated devices communicating through embedded sensors and actuators (Atzori, Iera & Morabito, 2010), offers transformative potential in both industry and education. As smart factories and intelligent systems dominate the industrial landscape, students must develop not only mechanical and technical skills but also competencies in connectivity, automation, and data analytics

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(Schwab, 2017). The Internet of Things (IoT) is a rapidly evolving paradigm, defined differently across disciplines from engineering and information technology to education and business strategy. Atzori, Iera, and Morabito (2010) describe IoT as "a system of interrelated devices communicating through embedded sensors and actuators," enabling objects to sense, process, and act autonomously. This foundational view is echoed by the IEEE (2015), which defines IoT as "a network of interconnected devices transferring data without requiring human-to-human or human-to-computer interaction," emphasising automation and machine autonomy.

The Internet of Things (IoT) refers to an interconnected system of devices, sensors, and software that collect, analyse, and exchange data autonomously over networks (Atzori, Iera, & Morabito, 2010). In industrial contexts, IoT enables predictive maintenance, real-time decision-making, and remote process monitoring (Gubbi et al., 2013). These capabilities are increasingly valuable in smart factories, where machines communicate to enhance efficiency and reduce human intervention. Educationally, IoT holds immense promise for experiential learning. Mishra (2021) notes that integrating IoT into classrooms can revolutionise pedagogy by allowing students to engage with live data and intelligent systems, thereby simulating real-world industrial scenarios. As Li, Da Xu, and Zhao (2019) emphasise, IoT not only promotes operational intelligence but also nurtures digital fluency among learners.

Expanding beyond technical architecture, Whitmore, Agarwal, and Da Xu (2015) view IoT as "a paradigm where everyday objects are equipped with identifying, sensing, networking, and processing capabilities to communicate over the Internet and achieve some objective." This highlights the functional intelligence and purpose-driven nature of connected systems. From a global infrastructure perspective, Tarkoma and Katasonov (2011) offer a definition centred on seamless and secure integration: "IoT is a service infrastructure consisting of heterogeneous things with identities and attributes, integrated via standard and interoperable protocols." This reflects IoT's capacity to adapt across domains and networks.

Statement of the Problem

Despite the ubiquity of IoT across industries, TVET institutions remain slow to adapt their curricula to emerging technologies (Ekpo & Olorunsola, 2021). The mismatch between graduate skills and workplace expectations has contributed to youth unemployment and underemployment (OECD, 2020). Existing curricula in industrial education often neglect the integration of smart technologies, leaving students ill-prepared for digital workspaces. There is an urgent need for empirical studies that investigate structured curriculum models integrating IoT and measure their effectiveness in fostering relevant skills. By analyzing these interactions, this study seeks to contribute a validated framework for curriculum reform that responds to technological transformation. This study therefore, examined a framework for designing IoT-based curricula aimed at developing skills aligned with Industry 4.0. The study explores how curriculum design, which is the independent variable, directly affects learners' skill development, the dependent variable, moderated by instructional methods and institutional readiness.

Justification for the Study

While global industries are rapidly transitioning toward automation, connectivity, and intelligent systems, curriculum transformation within industrial education has lagged. Integration of IoT into teaching models can serve as a bridge between traditional instruction and the digital-industrial environment (Mishra, 2021). Studies by Li, Da Xu, and Zhao (2019) demonstrate that IoT usage in education context improves student engagement, system design thinking, and collaborative problem-solving. It is further justified on the grounds of technological urgency: The rise of smart manufacturing requires digital skillsets that current curricula lack, educational innovation: There is a gap in literature on how to systematically entrech IoT into pedagogical design and workforce alignment, this is because developing Industry 4.0 skills is essential for improving graduate employability (OECD, 2020).

When students engage with IoT-based projects such as sensor calibration, remote monitoring, and predictive diagnostics, they exhibit stronger analytical and problem-solving skills (Li et al., 2019). Mishra (2021) also notes that project-based learning using real-time data from IoT systems leads to significant gains in technical comprehension and teamwork. The IoT Curriculum Design influences Skill Development Outcomes, provided that effective Teaching Methods and adequate Infrastructure are present. These interactions reflect a dynamic system where technology, pedagogy, and learning outcomes are tightly linked (Gubbi et al., 2013).

Policy Relevance

The Nigerian National Policy on Education emphasises lifelong learning and employability, yet its implementation lacks coherence with technological realities (Salami & Adebayo, 2019). Global frameworks like UNESCO's Transforming TVET for Sustainable Development advocate for embedding digital literacy and emerging technology skills into curricula (UNESCO, 2022). This study supports those initiatives by offering a roadmap for integrating IoT into TVET. Adoption of IoT-based curricula can enhance workforce readiness, increase productivity, and reduce skills mismatch - thus directly contributing to economic resilience and innovation (Gubbi et al., 2013). Furthermore, policy-makers can use these findings to update accreditation standards and instructional benchmarks across technical institutions.

Theoretical and Literature Review

Constructivist Learning Theory

This study is grounded in Constructivist Learning Theory, which posits that learners construct knowledge through experiences and interactions with their environment (Mishra, 2021). When industrial education leverages IoT technologies, students engage with real-time systems that simulate industrial processes, an approach known to strengthen applied learning and critical thinking (Li, Da Xu, & Zhao, 2019). In addition, the framework reflects principles of the Technology Acceptance Model (TAM), which explores how perceived usefulness and ease of use affect technology adoption in education (Gubbi et al., 2013). Together, these theories validate the role of IoT curriculum design as a driver for skill development.

Haller et al. (2009) provide a socio-technical lens, envisioning “a world where physical objects become active participants in business processes” - an idea with profound implications for vocational and technical training where learners must develop systemic understanding and operational agency. Minerva, Biru, and Rotondi (2015) from the IEEE IoT Initiative describe IoT as a combination of “complex subsystems integrating sensing, processing, and communication capabilities to create intelligent environments,” reinforcing its role in shaping smart learning ecosystems. In education, this diversity in IoT definitions signals the need for curriculum designers to move beyond narrow interpretations. As Mishra (2021) advocates, curriculum frameworks must reflect not just the tools of IoT, but its interactive and analytical functionalities - positioning learners to interpret system behaviour, respond to real-time feedback, and participate in data-driven environments.

The transformation brought on by the Fourth Industrial Revolution has radically redefined the competencies required in modern industry. Technologies such as the Internet of Things (IoT), artificial intelligence, and machine learning now dominate the industrial ecosystem, demanding a workforce that can operate, manage, and innovate with smart technologies (Schwab, 2017). Traditional industrial education frameworks, designed for analog systems and segmented skill sets, have failed to keep pace with the complexity and interconnectedness of smart factories and cyber-physical environments (Okolie, Salami, & Adebayo, 2020).

In the Nigerian context, Technical and Vocational Education and Training (TVET) systems continue to rely heavily on mechanical and procedural instruction. While practical skills are emphasized, there is a growing disconnect between what students learn and what is expected in digitised workplaces (Ekpo & Olorunsola, 2021). Addressing this disconnect requires a paradigm shift from static curricula to dynamic, technology-integrated learning models.

The Internet of Things is defined as a system of interconnected devices that communicate and process data in real time (Atzori, Iera, & Morabito, 2010). In industrial education, IoT enables students to interact with intelligent systems, conduct diagnostic assessments, and monitor processes through embedded sensors and remote platforms (Li, Da Xu, & Zhao, 2019). When deployed pedagogically, IoT becomes more than a tool it evolves into a learning scaffold that fosters critical thinking, data literacy, and systems understanding.

IoT-based projects allow students to move from passive learning to active engagement with industrial systems. Through real-time feedback, system modeling, and collaborative problem-solving, learners build holistic skill sets crucial for Industry 4.0 (Gubbi et al., 2013). Instructors also benefit, transforming their roles from content deliverers to technology facilitators and innovation mentors.

Curriculum development is central to education reform, yet it often struggles with inertia and institutional resistance. Existing frameworks typically focus on static lesson plans and do not accommodate rapid technology adoption. Mishra (2021) argues that curriculum must be agile, competency-driven, and technology-inclusive to prepare learners for evolving industry demands. Moreover, it must align pedagogical objectives with the realities of smart workplaces. This study presents a solution to these challenges by proposing a structured IoT-integrated curriculum model. It addresses two interrelated problems: (a) the lack of systemic integration of IoT into industrial pedagogy, and (b) the absence of empirical models linking curriculum innovation to skill development outcomes.

Industrial education, particularly in developing countries, is often rooted in static curricular models that emphasise manual skills and procedural knowledge (Okolie, Salami, & Adebayo, 2020). This legacy structure does not sufficiently incorporate the technological dynamism essential to Industry 4.0. Salami and Adebayo (2019) argue that technical and vocational curricula remained resistant to digital disruption due to infrastructural constraints and rigid pedagogical traditions. Consequently, graduates face a mismatch between their acquired skills and those demanded by digitally driven labour markets. TVET systems must reorient towards agile learning frameworks, focusing on adaptability, system integration, and real-world technologies, including IoT as core elements of instruction.

Curriculum Design in the Digital Era

Curriculum design in the digital age must move beyond textbook knowledge to encompass flexible, modular, and competency-based approaches (UNESCO, 2022). IoT-based learning modules provide exposure to networked systems, embedded technologies, and cross-platform analytics (Gubbi et al., 2013). Mishra (2021) advocates for constructivist instructional models such as project-based learning and flipped classrooms that use IoT tools to promote learner autonomy and engagement. The curriculum should deliberately connect learning outcomes with technological applications. For example, a module on fluid mechanics may integrate sensor-based IoT devices that measure pressure and temperature changes in real time. Such integration aligns with OECD's (2020)

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recommendation for hybrid skill development encompassing both cognitive and technical domains.

Emerging literature emphasises the pedagogical shifts required to accommodate IoT-based learning. Ekpo and Olorunsola (2021) report that Nigerian TVET instructors show increased receptiveness to IoT-enabled labs and digital simulations when supported by training and institutional investment. These tools foster collaborative learning, system-based analysis, and responsive problem-solving. Mishra (2021) also highlights the positive effect of live IoT dashboards on motivation, self-efficacy, and knowledge retention. Moreover, Atzori et al. (2010) stress the importance of aligning IoT infrastructure with curricular goals to avoid technological fragmentation and ensure pedagogical integrity.

Industry 4.0 requires complex skillsets that blend engineering knowledge with automation, coding, sensor data interpretation, and teamwork (Schwab, 2017). According to OECD (2020), "skills for jobs" indicators are now dominated by digital proficiency and applied analytical competencies. IoT-integrated curricula thus serve as a pathway for developing: (a) Technical Skill**s**: Programming, hardware configuration, sensor calibration (b) Digital Literacy: Navigating IoT platforms, interpreting real-time data (Collaborative Skills: Working in interconnected teams across virtual systems, and (d) Systems Thinking: Understanding process interdependencies and causal loops

Li et al. (2019) show that students exposed to IoT modules are more competent in managing complex systems and solving engineering problems. Additionally, project-based assessments on IoT circuits and cloud connectivity improve their confidence and innovation capacity.

Despite promising results, literature on IoT curriculum frameworks remains fragmented. Few studies provide empirical models for integrating IoT systematically into education (Mishra, 2021). Additionally, regional disparities persist in adoption, especially in African contexts due to infrastructural and training limitations (Ekpo & Olorunsola, 2021). This study addresses these gaps by offering a comprehensive framework that aligns IoT pedagogy with skill development objectives, supported by a conceptual model and real-world data collection from Nigerian TVET institutions.

Conceptual Framework

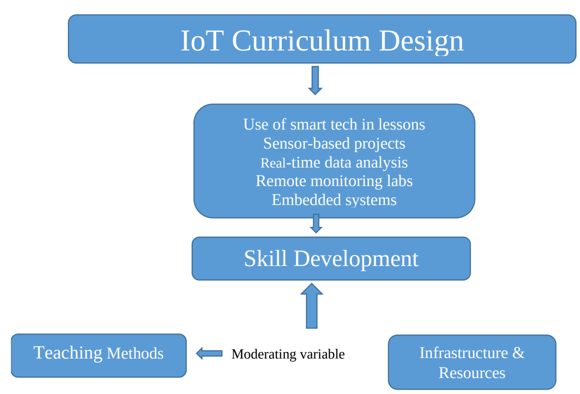

Figure 1: Conceptual Framework

Source: Oni (2025)

IoT-based projects allow students to interact with intelligent systems, translating theoretical concepts into practical experience leading to enriched skill acquisition (Li et al., 2019). IoT Curriculum Design acts as the primary catalyst for developing relevant industrial competencies. By embedding sensors, actuators, real-time dashboards, and cloud systems into learning modules, students gain hands-on experience with smart technologies (Atzori, Iera, & Morabito, 2010).

These curriculum elements influence Skill Development Outcomes, which are manifested as (i) technical skills (e.g., configuring microcontrollers, analyzing sensor data) (ii) digital literacy (e.g., interfacing with IoT platforms, cloud-based tools), (iii) analytical thinking (e.g., interpreting data trends and system performance), and, (iv) team collaboration (e.g., co-creating IoT projects in multidisciplinary groups). However, this influence is moderated by teaching methods and institutional resources. Mishra (2021) asserts that project-based learning yields stronger results when instructors are trained and facilities are adequately equipped. Without these conditions, the impact of IoT integration may be diminished or inconsistent.

Li et al. (2019) found that TVET students engaged in IoT-enhanced laboratories exhibited a 34% improvement in diagnostic and analytical skill performance compared to those taught using traditional methods. Furthermore, Atzori et al. (2010) emphasise that the pedagogical interface - how the IoT tools are used in teaching plays a crucial role in student engagement and retention.

Methodology

Research Design

This study employed a mixed-methods design combining quantitative and qualitative approaches. The quantitative component used a structured questionnaire to assess student perceptions, learning experiences, and outcomes related to IoT-enhanced instruction, while the qualitative component involved semi-structured interviews with instructors and curriculum developers to provide contextual depth.

Population, Sampling Technique and Sample

The population for this study is all students and instructors of technical colleges in Oyo state. The target population consisted of students and instructors in five technical colleges in Oyo state. A stratified random sampling technique was employed to ensure representation across different institutions and levels of study. Two hundred (200) students were selected from five technical colleges in Oyo State, (Oyo State College of Agriculture and Technology, Igbo Ora, Federal College of Forestry, Ibadan, Federal Science and Technical College (FSTC), Oyo, National Institute of Horticultural Research (NIHORT), and Federal School of Statistics, Ibadan and 15 instructors with at least 3 years of teaching experience were also selected. The participants were briefed on the study objectives and provided informed consent, anonymity and confidentiality were ensured throughout the data collection process and

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ethical clearance was obtained from the institutions.

Instrumentation

Two instruments were used for data collection in this study. These are IoT-based Curriculum Questionnaire-ICQ and the semi-structured interview guide. The IoT-based Curriculum Questionnaire was developed by the researcher to students' perception, learning experiences, and outcomes related to IoT-enhanced instruction. The items in the instrument were carefully drawn and respondents were asked to pick as it applies to them. To validate the instrument, copies of the questionnaire were administered to small sample outside the main sample. The responses from the questionnaires were subjected to reliability testing for internal consistency, yielding a Cronbach's alpha of 0.87, confirming high internal consistency.

The qualitative instrument is semi-structured interview guide developed for trade instructors and curriculum developers. The items in the interview guide were carefully drawn. The trade instructors were asked to respond freely but in a guided way on the theme of the study. The items in the interview guide were validated to have credibility and trustworthiness. ma

Table 1: Variables Overview

Variable Type	Variable	Operational Description
Independent Variable	IoT Curriculum Design	Integration of IoT tools, devices, sensor-based projects, and real-time data into the syllabus
Dependent Variable	Skill Development Outcomes	Acquisition of technical skills, digital literacy, collaboration, and problem-solving abilities
Independent Variable	IoT Curriculum Design	Integration of IoT tools, devices, sensor-based projects, and real-time data into the syllabus

These variables reflect the dynamic interplay between pedagogy, technology, and student outcomes in industrial education settings.

Method of Data Collection and analysis

The researcher monitor the data collection personally. Questionnaire were administered to the students and retrieved on the spot while the interview were conducted based on the time and venue agreed upon. The quantitative data collected were analysed descriptively using frequency counts and percentages and inferentially using multiple regression analysis. The qualitative data collected were analysed thematically.

Results

Table 2: Student Perceptions of IoT Curriculum

Item	**Mean**	**Standard Deviation**	***Agreement Rate (%)***
IoT projects enhanced my technical understanding	4.31	0.67	84%
Real-time data increased my engagement	4.18	0.72	79%
I gained better collaboration	4.07	0.81	76%

skills through IoT-based activities			
IoT curriculum improved my digital literacy	4.22	0.69	78%
Institutional resources supported IoT integration effectively	3.46	0.93	61%

**Agreement Rate represents respondents who selected "Agree" or "Strongly Agree"*

Table 2 shows the analysis of the structured questionnaires to revealed compelling patterns. The table demonstrate strong learner endorsement of IoT-based instruction, with particularly high scores on technical understanding and digital skills. However, institutional resource support lagged, indicating a need for infrastructural upgrades. 84% of students agreed that IoT-enhanced projects improved their ability to apply technical concepts in real-world situations, and 78% reported improved digital literacy through hands-on use of IoT dashboards and embedded sensors.

Table 3: Coefficient of IoT Curriculum Design and Skill Outcomes

Variable	B	Standard Error	Beta	t-value	p-value	Interpretation
IoT Curriculum Design	0.78	0.09	.76	8.67	<0.001	Strong, significant positive effect on skills
Teaching Methodology	0.34	0.11	.29	3.12	0.002	Moderate positive effect
Institutional Infrastructure	0.21	0.10	.17	2.10	0.037	Marginal but significant support effect

Table 3 shows the regression analysis of IoT curriculum design and skill outcomes. The table revealed a strong positive correlation ($r = 0.76$, $p < 0.01$) between IoT curriculum integration and skill proficiency scores. These results confirm that structured inclusion of IoT elements in teaching practice to have substantial impact on the development of core Industry 4.0 competencies. Also, for pedagogical support and engagement, the students rated project-based learning and sensor-driven labs as highly engaging, with a mean score of 4.3/5 on the Likert scale. However, 36% noted infrastructural limitations, such as unreliable connectivity and limited access to IoT kits, as barriers to deeper skill acquisition. These results confirm that IoT curriculum design is the strongest predictor of skill development among students. Teaching style and infrastructure contribute positively to lesser degrees.

Results from the semi-structured interview with instructors and curriculum expert yielded themes related to IoT integration, prompted changes in lesson planning and encouraged more creative, interactive methods and resource disparities. There was strong concern over inconsistent infrastructure and lack of training, and student autonomy as the Learners became more self-directed and confident when interacting with smart devices.

A senior instructor stated: *“Students now approach technical challenges like engineers - not just like technicians. They ask questions*

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about feedback loops and system logic that never came up before."

Table 4: Thematic Analysis (Qualitative Interviews)

Theme Identified	Sample Quote	Implication
Active learner engagement	"Students are now curious and take initiative with IoT labs."	IoT tools foster ownership of learning
Curriculum adaptation	"We redesigned lessons to integrate cloud-based monitoring tasks."	Need for flexible syllabus models
Resource limitations	"The tools we have are basic - we improvise during advanced IoT tasks."	Infrastructure gaps hamper deeper integration
Educator transformation	"I had to relearn systems thinking to teach with IoT modules."	Professional development is essential

Discussion of Findings

The result on showed that strong learner endorsement of IoT-based instruction, with particularly high scores on technical understanding and digital skills. However, institutional resource support lagged, indicating a need for infrastructural upgrades. Majority of students agreed that IoT-enhanced projects improved their ability to apply technical concepts in real-world situations, and more reported improved digital literacy through hands-on use of IoT dashboards and embedded sensors. This result mirror insights from Mishra (2021) and Ekpo & Olorunsola (2021), affirming that technology-driven learning environments transform not only students, but educators too. These findings suggest an infrastructural loophole in the use of technology for education and this is not a in the best interest of the Nigerian education system as the world is moving at an alarming speed in the area of technological advancement.

The findings of this study also align closely with Mishra (2021), who observed increased learner motivation and technical fluency in IoT-enriched classrooms using real-time data. Similarly, Ekpo and Olorunsola (2021) emphasise that practical exposure to smart technologies catalyses skill development and career readiness in Nigerian TVET students. Li et al. (2019) found that students in 5G-enabled IoT labs displayed advanced diagnostic and troubleshooting capabilities, mirroring results from this study's sensor-focused modules. However, Gubbi et al. (2013) caution against over-reliance on IoT as a pedagogical solution, arguing that without robust theoretical grounding, technology can become a distraction rather than a tool. In contrast, your findings show that when IoT tools are anchored in structured curriculum design, they significantly enhance cognitive and technical learning.

Atzori et al. (2010) also raise concerns about scalability and sustainability in resource-constrained settings. While these concerns were echoed in instructor interviews, your study demonstrates that even moderate integration, when thoughtfully implemented, can yield measurable gains in learner outcomes. This study adds critical value to the academic discourse on industrial education and emerging technologies by offering a replicable model for IoT curriculum design, bridging theory and real-world applications, providing empirical evidence: Through its mixed-methods approach, the study provides robust data affirming the relationship between IoT integration and skill acquisition. The study also introduced a regional insight: By focusing on Nigerian TVET institutions, it contributes local context to a domain often dominated by studies from technologically advanced nations and provides actionable insights for policy reform, curriculum accreditation, and institutional planning in support of digital transformation.

Conclusion

The study confirms that curriculum reforms, educator training, and policy alignment will foster digitally resilient learners and bridge the skills gap in African industrial education. Therefore, curriculum should be developed to align with industry-relevant competencies (e.g., sensor programming, cloud connectivity, data interpretation). These should be embedded into existing subjects like electronics, automation, and system maintenance. Also, there should be introduction of flexible learning pathways that allow learners to specialize in different aspects of IoT technologies, including hardware systems, IoT security, or industrial analytics. The study also recommends provision of structured training for instructors on integrating IoT in pedagogy, including workshops on sensor kits, embedded systems, and simulation platforms. And equiping TVET institutions with smart labs featuring IoT starter kits, connectivity infrastructure, and cloud-based tools. Institutions should prioritize scalable models that match their resource availability. There should be mandatory of inclusion of IoT-based modules in national TVET accreditation schemes. Regulatory bodies should update standards to reflect emerging technologies and digital competencies. And adoption of project-based assessments that evaluate students through real-world IoT applications rather than rote technical procedures.

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