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Exploring STEM-TVET integration in technical colleges: middle leaders' experiences

Sulaimon Adewale[1], Nurudeen Babatunde Bamiro[2] and Ntokozo Dennis Ndwandwe[1]

[1]*Department of Educational Foundations, College of Education, University of South Africa, AJH van der Walt Building, Muckleneuk Campus, Preller Str., Muckleneuk Ridge, Pretoria, Gauteng, South Africa*

[2]*Department of Language, Arts and Social Science Education, Lagos State University, Ojo-Badagry Expressway, P.M.B. 001, G.P.O. Ojo, Lagos, Nigeria*

Abstract. The need to prepare students with 21st-century skills has led to global educational reforms, including integrating Science, Technology, Engineering, and Mathematics (STEM) into Technical and Vocational Education and Training (TVET). This study explores how middle leaders in Nigerian technical colleges perceive and implement STEM-TVET integration. Using a qualitative approach, 15 purposively selected middle leaders from government-owned technical colleges in Lagos, Nigeria, comprising heads of departments, vice principals, and year tutors, were interviewed. Semi-structured interviews captured their experiences and insights, and data were thematically analysed using NVivo software. Three themes emerged: (1) Middle leaders' conceptualisation of STEM-TVET integration and its benefits, (2) Systemic barriers to effective implementation, and (3) Strategies for sustainable enhancement. Findings indicate that while STEM-TVET integration enhances employability, innovation, and critical thinking, barriers such as outdated curricula, inadequate teacher training, and infrastructural deficits hinder progress. Improvement strategies include human capital development, innovative funding models, policy localisation, and societal reorientation toward STEM.

Keywords: STEM-TVET, middle leaders, technical colleges, developing country

1. Introduction

In recent years, the global education landscape has significantly shifted towards prioritising Science, Technology, Engineering, and Mathematics (STEM) disciplines as essential drivers of economic growth, technological innovation, and societal development. This paradigm shift reflects the increasing recognition that STEM education equips individuals with the skills, knowledge, and mindset necessary to navigate the complexities of the modern world. In Nigeria, like many other nations, the integration of STEM education within the context of Technical and Vocational Education and Training (TVET) has emerged as a critical endeavour to address the challenges and opportunities of the 21st century.

Nigeria, one of Africa's largest economies, recognises the urgent need to enhance its technical and vocational education sector to meet the demands of a rapidly evolving global economy. Technical colleges, which are a cornerstone of the TVET system, play a vital role in equipping students with practical skills that align with the requirements of

0000-0003-2271-7443 (S. Adewale); 0000-0001-8298-8275 (N. B. Bamiro); 0000-0001-7149-2397 (N. D. Ndwandwe)
sulady.sa@gmail.com (S. Adewale); bamiro01@gmail.com (N. B. Bamiro); ndwannd@unisa.ac.za (N. D. Ndwandwe)
https://scholar.google.com/citations?user=5H2YJRUAAAAJ (S. Adewale); https://lasu.edu.ng/home/academic-staff/profile/?name=BAMIRO-NURUDEEN (N. B. Bamiro); https://www.unisa.ac.za/sites/corporate/default/Colleges/Education/Schools,-departments,-centres-&-instutes/School-of-Educational-Studies/Department-of-Educational-Foundations/Staff-members/Dr-ND-Ndwandwe (N. D. Ndwandwe)

various industries [2, 3, 49]. However, the changing technological landscape requires adjusting the curriculum to ensure students are adequately prepared to engage with emerging industries and innovations. Integrating STEM principles into the TVET framework represents a progressive approach to addressing this challenge [20, 42, 47]. By incorporating STEM concepts into technical education, students are exposed to cross-disciplinary learning that fosters problem-solving skills, critical thinking, and creativity. STEM-oriented TVET programmes prepare students for immediate employment, empower them to adapt to a rapidly changing job market, and contribute to the nation's technological advancements.

Several factors underline the significance of enhancing STEM integration in Nigerian technical colleges. First, Nigeria's youthful population presents both a demographic dividend and a potential challenge [23, 38]. Leveraging STEM education in TVET can harness the energy and enthusiasm of the youth towards productive and innovative endeavours. Second, the nation's economic diversification agenda emphasises agriculture, information technology, renewable energy, and manufacturing sectors. A workforce skilled in STEM disciplines is indispensable for the success of these sectors. Lastly, global trends in education emphasise hands-on learning, project-based approaches, and experiential learning, all of which are inherent in both STEM and TVET methodologies. However, challenges remain. Adequate infrastructure, qualified educators proficient in technical subjects and pedagogical methods, and up-to-date curricula are prerequisites for effective STEM integration in TVET. Additionally, there is a need for robust public-private partnerships that can provide students with real-world experiences, mentorship, and exposure to cutting-edge technologies.

1.1. Statement of the problem

Despite the growing global emphasis on STEM education, significant challenges persist in understanding and addressing STEM perceptions, preparedness, and educational outcomes among educators and students, particularly in developing countries [51]. While there is increasing recognition of the importance of STEM integration in educational systems, empirical research remains limited in investigating the prior beliefs, perceptions, and effectiveness of STEM education initiatives, especially in the context of underrepresented populations and TVET programmes [42]. Furthermore, existing studies often fail to provide comprehensive evaluations of the impact of STEM interventions [27], resulting in a gap between theoretical aspirations and practical outcomes in STEM education implementation. This research addresses these gaps from the perspectives of middle leaders by examining the barriers and opportunities associated with STEM education, particularly focusing on its integration in TVET and its implications for equitable participation and workforce development, thereby contributing to more informed policy and practice in educational settings worldwide.

1.2. Research questions

The following questions are raised in this study:

1. What are middle leaders' understanding of STEM-TVET integration in technical colleges in Nigeria?
2. What are the benefits of integrating STEM in TVET in Nigeria?
3. Are there barriers to STEM-TVET integration in Nigeria?
4. What are the strategies for enhancing STEM-TVET integration?

2. Literature review

2.1. STEM education

During the 1990s, the National Science Foundation brought together the fields of science, technology, engineering, and mathematics under the acronym STEM. Initially, these disciplines were combined using the acronym SMET (Science, Mathematics, Engineering and Technology), which was later changed to STEM for phonetic reasons. This effort was driven by the perceived necessity to enhance the STEM skills of young individuals and adults, aiming to uphold national economic competitiveness [29]. Furthermore, this strategy was adopted by scientists, technologists, engineers, and mathematicians to establish a more unified and influential political presence. One notable early result of this approach was the establishment of the first STEM Education Degree in 2005 by Virginia Tech University. This degree program aimed to emphasise the vital role of education in ensuring the effective delivery of appropriate STEM training [31]. After this development, the acronym gained significant international recognition within the realm of education [29].

According to Pimthong and Williams [40], STEM involves the fusion of science, technology, engineering, and mathematics, with applications extending to professional endeavours and everyday encounters. The significance of STEM emerges from the interconnectedness of these fields within the fabric of the world, as they unite to address intricate and multifaceted challenges that are universally experienced. Similarly, Kefalis and Drigas [25] assert that STEM embodies the integration of science, mathematics, engineering, and technology, emphasising their interconnected nature rather than separate entities. This educational strategy strives to blend these domains through hands-on, experiential tasks that mirror real-life situations.

STEM education, a progressive teaching approach, prepares individuals for their forthcoming lives and careers by imparting knowledge in science, technology, engineering, and mathematics [16]. All individuals must be well-versed in these subjects, particularly for young learners, to engage in multifaceted projects that integrate various disciplines. Such an integrated approach enhances learning outcomes and enables individuals to tackle diverse challenges [15]. STEM education entails students applying the mathematical and scientific principles they have learned within a practical framework facilitated by integrating engineering design and technology. Instead of being taught in isolation, the practical application of mathematical and scientific concepts emerges from the necessity to address real-world challenges, thereby infusing vitality into these subjects [9].

The foundation of STEM pedagogy also steers students towards a deeper understanding of the subject matter, achieved through resolving ambiguously defined problems [30]. At its core, STEM education highlights the importance of establishing links between theoretical knowledge and the practical hurdles encountered in the actual world. These connections serve as the cornerstone for seamlessly integrating science, technology, engineering, and mathematics subjects into the educational curriculum. The significance of STEM education is underscored by its pivotal role in equipping students with the skills required for the evolving workforce, thereby facilitating their entry into sought-after STEM professions that will shape the future [52].

Furthermore, the complexity of modern challenges spanning diverse fields accentuates the need for individuals and societies to possess a strong scientific and technological literacy foundation, further amplifying the importance of STEM education [35]. The World Economic Forum has acknowledged the competencies fostered through STEM education as a measure of a country's preparedness for upcoming challenges [43]. STEM education has witnessed rapid global evolution, with the synergistic integration of science, technology, engineering, and mathematics showing great promise in enhancing educational standards. This approach not only cultivates proficiency in technological innovation, design, and implementation but also nurtures the application of interconnected knowledge to address intricate challenges [16].

STEM education emerges as a pioneering methodology prominent in global educational policies and reforms [35]. Beyond merely fulfilling the objectives of educational reforms, which include strengthening mathematical and scientific proficiency, this approach highlights the necessity for individuals to not only grasp these concepts in isolation but also to integrate them with insights from technology and engineering [11]. Based on a learner-centric model, STEM education fosters learners' autonomy, critical thinking, collaborative abilities, and project management skills [46].

The essence of STEM Education lies in its capacity to prepare individuals for their forthcoming lives and careers [15]. This approach is particularly vital in the 21st century, as globalisation and rapid advancements in Information and Communication Technology (ICT) reshape societal landscapes, necessitating individuals equipped with STEM knowledge to meet evolving job demands [19]. On a global scale, STEM education has become closely intertwined with its functional and utilitarian principles that drive economic growth and efficiency. The integration of STEM disciplines is closely associated with the concept of 'innovation' across scientific, technical, and mathematical domains [48]. For instance, Papadakis and Orfanakis [39] demonstrated that practical approaches (e.g., robotics and coding projects) significantly improved problem-solving skills and engagement when teaching programming to Greek secondary students. This aligns with Nigeria's need for experiential STEM methodologies that bridge theory and application.

According to Timms et al. [50], STEM is indispensable in addressing concrete global challenges, and individuals equipped with strong STEM literacy are crucial for effectively addressing the complex issues our world faces. In a world grappling with escalating challenges in areas like agriculture, energy, medicine, and the environment, the significance of STEM education remains paramount in fostering inventive resolutions [43]. STEM literacy represents an urgent economic concern. The impending need for national productivity necessitates a workforce capable of occupying STEM-related positions, essential to withstand global competition [50].

2.2. STEM and TVET education in Nigeria

TVET and STEM education are pivotal to Nigeria's socio-economic and industrial transformation. TVET, designed to provide industry-relevant skills and practical competencies, aligns with the aspiration to develop a skilled workforce capable of driving innovation and productivity. Olabiyi and Uzoka [37] underscores the importance of effective policy frameworks, employer engagement, and competency-based training to strengthen TVET's contribution to sustainable industrial development. Similarly, STEM education has long been an integral component of the Nigerian educational system, encompassing the fields of science, technology, engineering, and mathematics [5]. Recognising its significance, STEM education is pivotal in fostering the nation's economic, social, political, and technological progress. Its contribution to Nigeria's economic landscape, societal advancement, and industrial growth is substantial. This form of education is ingrained within the country's universal basic education program, extending from basic schools to junior secondary schools [21]. Like other countries worldwide, Nigeria is progressively dependent on STEM to secure its position within the global economy [32].

The STEM education landscape in Nigeria has transformed since the nation's independence and continues to evolve. Nevertheless, multiple studies have linked the hurdles of sustainable development within Nigeria to issues concerning STEM education [26]. Compared to certain developed nations, the trajectory of STEM in Nigeria exhibits notable accomplishments in its history, yet it currently faces significant challenges necessitating attention. STEM's journey in Nigeria demonstrates notable achievements in specific sectors of the economy, including health, agriculture, and telecommunications [5].

Presently, in Nigeria, students' academic performance in STEM subjects has raised apprehension among stakeholders within the education sector. Alarming statistics consistently resurface annually, contributing to the prevailing concern [51]. Relying excessively on certificates has emerged as a notable challenge within STEM education in Nigeria [1]. As a result, both educators and students have tended to overlook the essential skill sets necessary for fostering sustainable development in the 21st century. Among these crucial skills are employability and scientific literacy skills. Furthermore, the prevailing instructional approaches in Nigerian public schools prioritise certificates over skills, causing STEM education to gradually deviate from its intended role of facilitating employment opportunities [17].

Despite recent initiatives like Nigeria's National TVET Policy [49] and STEM-industry partnerships, these systemic challenges persist largely unmitigated. Infrastructure gaps remain acute, with only 12% of technical colleges having functional computer labs [49]. Teacher competency deficits endure due to limited professional development, while misalignment between curricula and industry needs hinders graduate employability. Jacob [21] undertook a study investigating the obstacles encountered in STEM education in Nigeria. The study's outcomes reveal that Nigeria's administration of STEM education programs confronts various challenges. These challenges encompass insufficient infrastructural facilities, a shortage of qualified science teachers, insufficient instructional materials, inadequate motivation, limited funding, subpar supervision, a high student population, deficient capacity development initiatives for science teachers, and a negative disposition among students towards STEM education programs. Umar [51] research findings highlighted several areas that require improvement to achieve STEM objectives in Nigeria. These areas encompass innovative teaching methods, the establishment of additional universities and technical colleges, the creation of science equipment centres, the standardisation of syllabi, and other relevant measures. The limitations mirror challenges in the TVET system where poor policy implementation, fragmented supervision, and lack of industry-aligned curricula hinder outcomes.

2.3. Role of STEM education in the development of the TVET sector

In recent times, TVET has increasingly emphasised STEM education [13]. Technical and vocational high schools have emerged as conducive learning environments for nurturing learners proficient in STEM disciplines [6]. In the rapidly evolving landscape of the 21st century, the increasing global demands have brought significant attention to the practices of STEM education and the corresponding funding requirements within the realm of TVET [6]. Recent employment growth and productivity trends highlight a gap between job creation efforts and the expanding labour force. Enhancing the awareness and enrolment of students in TVET colleges for STEM education is a crucial step that governments must take [10]. This initiative can potentially empower the youth with the essential skills required to contribute to infrastructure development. By promoting STEM education in TVET institutions, the nation can nurture a pool of skilled and experienced engineers [8].

Given these dynamics, there is a pressing need to prioritise the role of TVET in nurturing innovative individuals who can contribute solutions to drive economic growth [7]. Integrating STEM education has been shown to enhance academic achievement, self-efficacy, and interest in STEM careers among TVET students [7, 13, 53]. TVET is crucial in equipping students with valuable skills for successful employment [4, 6].

Creating a conducive learning environment is a vital aspect of effective STEM education, achievable through the physical and technical infrastructure of TVET. Integrating mathematics, science, and technology content in technical branches of TVET, such as industrial automation and mechatronics, offers an ideal context for STEM education [12].

For vocational and technical education to thrive, it must embrace a vision of innovation and meaningful application of knowledge across disciplines. Collaborations with industry partners and education policymakers are essential to equip students with the skills demanded by the workforce [6]. In modern advanced TVET programs, the demand for 21st-century skills goes beyond traditional curricula. These skills include critical thinking, problem-solving, communication, and collaboration. They require project-based learning and technological expertise. STEM knowledge is crucial to these competencies, and integrating these elements is a new aspect of 21st-century skills for TVET students. Understanding STEM's interconnectedness helps students grasp their TVET program content more deeply [42].

3. Methodology

This study adopted a generic type of qualitative research design. Qualitative research explores participants' understanding, perceptions, and subjective experiences with a particular issue. Using this method, the first-hand experiences of the participants are explored on the phenomena under study [14]. Unlike other phenomenology, ethnography and other forms of qualitative research design that strictly adhere to an established procedure, generic qualitative research is flexible.

The target population for this study is all middle leaders in the government-owned technical colleges in Lagos state, Nigeria. We selected 15 middle leaders from government-owned technical colleges in Lagos, comprising year tutors = 5, department heads = 5, and vice-principals = 5, purposively. These participants were selected because they are middle leaders who serve as intermediaries between two individuals, and they are reportable to other leaders within the colleges. Middle leaders have robust knowledge of new developments and access to training and education policy documents. Public educational institutions hold significance for this study due to the specialised training opportunities they typically afford to their teaching staff compared to privately owned schools.

We achieved data saturation during the interview session, as no new themes or insights emerged after the 15 interviews. This saturation point was confirmed through a systematic three-step thematic analysis, peer review, and verification of transcripts using NVivo software, ensuring that the collected data sufficiently captured the complexity of participants' experiences. Hence, the sample size was adequate to draw meaningful and credible conclusions based on the study's objectives.

Data was collected through an in-depth semi-structured interview with the participants to understand how STEM is integrated into the TVET in Nigeria technical colleges. The researchers prepared a semi-structured interview protocol to guide the interview process. The interview protocol comprised two sections, with the first seeking the participants' demographic details, while the second contained questions that addressed the research questions. The interview was conducted face-to-face, with each interview session lasting 15 minutes.

In the analysis, the researchers adopted a systematic three-step thematic approach. To delve into the subject's intricacies, semi-structured interviews were conducted with a purposively chosen group of 15 TVET instructors from government technical colleges in Lagos State, Nigeria. This purposeful selection ensured the participants possessed specific insights and experiences relevant to the study's objectives.

After completing the interviews, a meticulous and comprehensive verification of interview transcripts and accompanying field notes was carried out. The intention was to ensure that the gathered data was accurate and encompassed the depth and breadth necessary for a thorough analysis. This data validation process, aligned with the guidance of McGrath, Palmgren and Liljedahl [33], is paramount in establishing the credibility and reliability of qualitative data-driven exploration.

To scrutinise the generated data, the researchers embraced the peer review method advocated by Stahl and King [45]. This entailed subjecting the collected responses to scrutiny, validation, and evaluation by peers within the research community. Subsequently, the researchers embarked on the meticulous task of transcribing the interviews and conducting a rigorous review, during which they cross-referenced the content against the original audio recordings. This critical step was instrumental in uncovering pertinent key themes, a sentiment reinforced by Kamarudin and Adams [24]. At this stage, the amalgamation of related codes culminated in the emergence of overarching themes.

In the third phase of the analysis journey, the researchers harnessed the capabilities of the qualitative analysis tool QSR NVivo software version 1.7.1 to execute the final coding of the accumulated data. The selection of NVivo was predicated upon its user-friendly interface, methodical approach, and adaptability, all of which collectively contributed to the effective categorisation of data into distinct groupings and subgroups. Additionally, the software's functionalities facilitated the seamless data organisation within the pertinent thematic clusters, streamlining the subsequent analytical process. Notably, the coded data were systematically structured through parental and child nodes, creating a hierarchical arrangement that enhanced the clarity and coherence of the data representation.

Ethical issues were also addressed by securing the participants' informed consent. They were assured of anonymity and confidentiality. They had the right to withdraw at any stage of the study.

4. Results

The findings of this study are organised around three main themes that emerged from the analysis of interview data: the current understanding and rationale for STEM-TVET integration, perceived barriers to integration, and proposed strategies for effective implementation. These themes reflect the participants' insights based on their institutional roles and professional experiences. Results presentations start with an overview of participants' characteristics, followed by a presentation of findings aligned with each theme.

Table 1 provides an overview of the characteristics of participants involved in the study from government technical colleges in Lagos, Nigeria. The participants were teachers, referred to as instructors, who have been contributing to TVET in these institutions. The characteristics considered include gender, years of experience, academic qualifications, and the subjects they teach. The participants encompassed a diverse range of genders, with seven males and eight females contributing to the study. The years of experience among the participants varied, with their teaching careers spanning from 5 to 17 years. Their academic qualifications were indicative of a range of educational backgrounds, including Master of Science (MSc), Bachelor of Technology (BTech), Bachelor of Education (BEd), Higher National Diploma (HND), and Bachelor of Science (BSc). The subjects taught by the participants reflected the technical and vocational focus of the study, with subjects like Woodwork, Plumbing, Chemistry, Physics, Electrical, Mathematics, Textile, Building, and Automobile. The diversity in participant characteristics underscores the inclusivity of the study, capturing insights from instructors with different backgrounds and experiences within the context of government technical colleges.

4.1. Theme 1: Understanding the current state of STEM integration in TVET

Table 2 presents an overview of the findings related to the current state of STEM integration within the context of TVET in Nigeria. The table encompasses one main

Table 1
Participants' characteristics.

Participant ID	Gender	Years of experience	Academic qualification	Position	Subject taught
Participant 1	Male	12	MSc	HOD	Woodwork
Participant 2	Female	15	BTech	Unit head	Plumbing
Participant 3	Male	10	BEd	Year tutor	Chemistry
Participant 4	Male	6	HND	Unit head	Physics
Participant 5	Male	8	BSc	HOD	Electrical
Participant 6	Female	9	BSc	HOD	Mathematics
Participant 7	Male	13	MSc	Year tutor	Mathematics
Participant 8	Female	12	MSc	HOD	Textile
Participant 9	Male	10	BEd	HOD	Building
Participant 10	Male	11	BSc	HOD	Building
Participant 11	Male	11	BSc	HOD	Automobile
Participant 12	Male	17	BSc	HOD	Chemistry
Participant 13	Male	10	MSc	Vice principal	Automobile
Participant 14	Female	9	BSc	Vice principal	Electrical
Participant 15	Female	5	BEd	Year tutor	Electrical

theme: "Understanding the current state of STEM integration in TVET", which is divided into two sub-themes and associated factors.

Table 2
Understanding the current state of STEM integration in TVET.

Theme 1	Sub-theme	Factors	Frequency
Understanding the current state of STEM integration in TVET	Main reason for STEM in TVET	Fulfil workforce market demand	13
		Emphasis on innovation	12
		Capacity building of training	11
		Improve employability	14
		Encourages critical thinking	12
		Problem-based learning	10
	Benefits of STEM-TVET integration	Encourages self-employment	13
		Helps learners make informed decisions	11
		Promotes equality in education	9
		Provides sustainable solutions	12
		Shows real-world applications	14

The first sub-theme of understanding the current state of STEM integration in TVET delves into the reasons behind incorporating STEM within TVET programs. The study identified six main reasons for integrating STEM in TVET through the participants, including fulfilling workforce demands in the market, emphasising innovation, enhancing the capacity building of training, improving the employability of TVET graduates, fostering critical thinking skills, and promoting problem-based learning. Some of the participants expressed as follows:

> STEM-TVET integration bridges the gap between theory and industry. Without it, our graduates lack the innovative mindset needed for modern jobs. (Participant 8, HOD, Textile)

Similarly, another participant opined:

> We must align training with workforce demands. STEM makes our students problem-solvers, not just certificate holders. (Participant 14, Vice principal, Electrical)

Furthermore, the second sub-theme, the benefits of STEM-TVET integration, highlights the advantages resulting from integrating STEM principles into TVET. These benefits include incorporating hands-on learning experiences, enabling individuals to make informed decisions, promoting equality in education by offering opportunities for all, providing sustainable solutions to real-world challenges, and illustrating real-world applications of STEM concepts. The table 2 underscores the multifaceted nature of STEM integration in TVET, showcasing both the reasons behind its implementation and the potential benefits it offers to learners and the broader educational landscape.

> When students build a solar-powered device in class, they see how math and engineering solve real-life energy crises. That's transformative. (Participant 6, HOD, Mathematics)

4.2. Theme 2: Barriers to STEM-TVET integration

Figure 1 analysis of participants' responses revealed a range of systemic and institutional barriers that hinder the effective integration of STEM into TVET programs in Nigeria. As illustrated in figure 1, the most frequently cited challenges include outdated curricula that fail to reflect current industrial demands and a lack of adequately trained teachers who can effectively deliver STEM content. Participant 3 lamented:

> Teachers avoid STEM projects because they lack training. The government's curriculum is a decade behind industry. (Participant 3, Year tutor, Chemistry)

Infrastructural deficits such as inadequate laboratory equipment, poor internet connectivity, and insufficient learning spaces also emerged as critical impediments to delivering hands-on, technology-driven instruction. According to Participant 5:

> Our workshops still use analogue equipment. How can we teach automation without IoT tools? (Participant 5, HOD, Electrical)

Participants further noted that ineffective assessment frameworks and minimal stakeholder involvement in curriculum development have limited the responsiveness and adaptability of TVET programmes.

Additionally, socio-cultural factors, such as students' negative perceptions of STEM fields and a general undervaluing of vocational education, contributed to low enrolment and engagement. These barriers collectively point to comprehensive reforms in teacher training, curriculum design, infrastructure investment, and policy alignment to support a more integrated and future-ready STEM-TVET system.

4.3. Theme 3: Strategies for enhancing STEM-TVET integration

Table 3 outlines a comprehensive set of strategies proposed by participants to strengthen the integration of STEM within Nigeria's TVET system. A central recommendation involves aligning TVET programmes more closely with industry experiences through initiatives such as industrial placements and practical exposure, and ensuring that training content matches evolving skill demands. Curriculum restructuring was also emphasised, particularly the reorganisation and modernisation of outdated content to reflect technological advancements and industry needs. Participants stressed the importance of government support in motivating industrial participation, suggesting incentives such as tax concessions, infrastructure development, and policy

Figure 1: Barriers and challenges to STEM-TVET integration.

reforms enabling industries to contribute meaningfully to curriculum design and implementation. Human capital development is equally vital, especially through instructors' retraining and establishing mentorship programmes to enhance teaching quality and industry relevance. Respondents advocated for innovative funding models to address financial constraints, including public-private partnerships and targeted grants. According to Participant 13,

> Unless industries fund labs and co-design courses, STEM-TVET will remain theoretical. Tax breaks could motivate them. (Participant 13, Vice principal, Automobile)

In the same vein, Participant 9 suggested:

> We need monthly retraining, like how to teach A.I.-assisted design. Without this, instructors stick to chalkboards. (Participant 9, HOD, Building)

Additionally, they highlighted the need for policies to be localised, ensuring strategies are adapted to the specific socio-economic contexts of different regions. Finally, societal reorientation towards STEM was considered essential, with recommendations for public awareness campaigns and community engagement initiatives aimed at shifting public perception and increasing interest in STEM-related vocational careers.

Table 3
Strategies for enhancing STEM-TVET integration.

Main strategy	Sub-items
Align TVET with the experience with industry	Industrial placements, skill alignment, practical exposure
Curriculum restructuring	Course reorganisation, update of outdated curriculum
Government motivation of industries	Tax concessions, infrastructure provision, policy reform, curriculum input
Human capital development	Instructor retraining, mentorship programmes
Innovative funding	Public-private partnership, grants
Localisation of policy	Adaptation to local context, inclusive development
Societal reorientation towards STEM	Public awareness campaigns, community engagement

5. Discussion

This study explores middle leaders' perspectives on STEM-TVET integration in technical colleges. The first objective explores instructors' understanding of the rationale behind the integration of STEM in TVET. It was found that the integration of STEM into the curriculum of technical and vocational education and training is to fulfil the market workforce because of its emphasis on innovation. Hands-on workshop practices that modelled STEM will encourage the instructors to adjust their pedagogical practices to 21st-century needs [22]. Similarly, Mesutoglu and Corlu [34] emphasised that in the 21st-century classroom, every learner is expected to be involved in science and engineering practices in proffering solutions to world challenges. The participants' perspectives corroborate the definition of Shernoff et al. [44] on STEM integration as when science, technology, engineering, mathematics and their related practices establish a student-centred learning atmosphere to proffer an explainable panacea to global problems. This implies that every learner should know what goes on in other disciplines outside his/her primary area of specialisation.

The study found outdated curriculum, ineffective assessment, teachers' competency issues, and low stakeholder engagement in curriculum development to be the major barriers to STEM-TVET integration. This is in congruence with Akgunduz and Mesutoglu [6] that there is a mismatch between what employers want and what is offered in TVET institutions. Akgunduz and Mesutoglu [6] also found that TVET instructors' perception of the competency required for Industry 4.0 is low due to poor knowledge of STEM. As emphasised by a vice principal,

> Inadequate infrastructure forces us to skip entire robotics modules. Students graduate without touching a microcontroller. (Participant 13, Vice principal, Automobile)

This corroborates the findings by Akgunduz and Mesutoglu [6] that TVET instructors' low competency in Industry 4.0 tools stems from resource gaps.

Furthermore, it was found in this study that integration of STEM into the TVET curriculum will be of benefit to the individual learners and the society at large in terms of making learners self-employed, making informed decisions, providing sustainable solutions to global problems and showing real-world applications of the STEM offered solutions [20]. Through the integration of STEM, the 21st-century skills often demanded in many workplaces will be provided for the students. It will enable students to cope with unpredictable, complex problems because the skills are multidimensional. The study assembled the participants' suggestions on the best way to improve where it is already in operation and establish where it is not in practice, including integrating STEM in TVET teaching and learning. This research outcome aligns with Jaipal-Jamani, Mayne and Ibrahim [22], who found that interactive STEM workshops will enable TVET instructors to reimagine their teaching pedagogical design.

The study found human capital development, which comprises retraining instructors and mentoring on the need for STEM education and how to handle the dissemination of knowledge to the students. Supporting this finding, Mesutoglu and Corlu [34] made a case for the need to support teachers with the resources needed and localisation of the policy to implement STEM curriculum in schools successfully. A year tutor (Participant 3) argued that

> … localising policy is non-negotiable. Imported STEM kits fail in power-outage-prone labs; we need solar-powered alternatives. (Participant 3, Year tutor, Chemistry))

This aligns with Mesutoglu and Corlu [34] call for context-specific solutions. Guskey [18] emphasises the importance of ongoing teacher professional development to implement constructivist strategies in STEM-TVET integration effectively.

In addition, curriculum restructuring and provision of 21st-century experience for the learners were also identified as an enhancing strategy to achieve the integration exercise. This underscores the need to incorporate science, technology, engineering and mathematics components in the technical education curriculum. This will solve the mismatch problem between what is learnt in schools and the demands in the job market. Achieving this restructuring also requires course reorganisation [28] and weeding out obsolete courses. The study of Roehrig et al. [41] is in congruence with this finding that integrating STEM curricula will address global STEM initiatives and policies. Everlasting skills such as creativity, computational thinking, behavioural, social and quantitative skills [41] are essential hard and soft skills that must be considered in STEM-TVET integrated curricula.

6. Conclusion

This study has highlighted both the promise and the complexity of integrating STEM into technical education and training in Nigeria. Middle leaders from government-owned technical colleges provided rich insights into the current state of STEM-TVET integration, emphasising its potential to enhance employability, promote innovation, and align education with the demands of a rapidly developing economy. Despite the participant's exhibition of a convincing understanding of the values of integrating STEM into TVET in technical colleges, some areas of concern, including inadequate teacher training, infrastructure deficiencies and limited industry involvement, are enunciated as the barriers to integration that must be wiped out.

This study concludes that the ability of the education stakeholders to introduce strategic interventions, including curriculum reform, strengthened industrial partnerships, and instructors' capacity building, among others, will be instrumental in achieving the novel goal of STEM-TVET integration in Nigeria and other developing countries.

7. Limitations of the study

The generic qualitative method's subjective nature, which relies solely on the participants' experience and perceptions, is a limitation. It is often accompanied by individual bias, which limits the generalisability of the findings. Also, the inability to genuinely quantify the specific qualitative outcomes makes comparing findings with similar studies using quantitative methods difficult. The small sample size of this qualitative study can limit the generalisability of the findings.

The remaining barriers are language barriers, poor industrial experience, poor pedagogy, an unsolidified quality assurance framework, and social relegation.

8. Implications for education leadership and management

The findings of this study have the following implications. Firstly, integrating STEM into the TVET curriculum is essential to meet 21st-century workforce demands by emphasising innovation. The integration ensures that graduates possess relevant knowledge and skills that match the contemporary job markets, making them employable and capable of contributing to technological advancements. Furthermore, it implies the need for enhanced pedagogical practices. Establishing hands-on STEM workshops and practices will encourage TVET instructors to adapt their teaching methods to meet 21st-century educational needs. This shift in pedagogy is necessary to foster an environment where students are actively engaged in sciences and engineering practices, which are essential for solving modern world challenges.

Furthermore, students should be fortified with knowledge from disciplines outside their main area of specialisation. This broad-based understanding facilitates a holistic approach to problem-solving, enabling students to apply interdisciplinary knowledge to real-world issues. Thus, students are thereby prepared for complex and unpredictable problems in their professional endeavours.

The infrastructural gap also requires urgent attention. Nigeria's unreliable grid need not paralyse technical colleges. Deploying modular, solar-charged computer units with offline coding platforms ensures learning continues during blackouts. Partnering with NITDA's Digital Nigeria Initiative could extend satellite broadband to remote workshops, making cloud resources accessible even in Gashua or Ogoja. Such solutions acknowledge Nigeria's constraints while refusing to be defined by them.

Also, it implies the need to address curriculum and competency barriers. The alignment process faces significant challenges, including outdated curricula, ineffective assessment methods, and insufficient instructors' competencies. To overcome these, there is a need for curriculum updates, enhanced teacher training, and increased stakeholder engagement in curriculum development. Localising content through Nigerian case studies, such as Zaria's solar dryer initiatives or Lagos's waste-to-energy projects, will bridge theory with tangible community impact while advancing national diversification goals under Agenda 2050 [36]. Shifting societal perceptions requires speaking Nigeria's cultural language. National campaigns on national television channels and popular radio networks must spotlight relatable heroes: the female welder dominating Ariaria Market and the mechanic diagnosing faults with tablet-based diagnostics. Involving traditional leaders, the Obi of Onitsha, Oba of Lagos, or Sultan of Sokoto, to endorse technical careers taps into deep-seated communal respect. Their public blessings could reframe vocational work not as "plan B" but as a dignified path to build the next Benin City or Kano textile hub.

Retraining instructors and providing mentorship on the importance of STEM education are critical for successful integration. Continuous professional development and support for teachers are necessary to implement STEM teaching methodologies, ultimately benefiting students. Restructuring the curriculum to include more STEM components and providing students with real-world industrial experiences are vital. This approach addresses the mismatch between academic learning and job market demands, ensuring students acquire relevant skills. Courses should, therefore, be reorganised, and outdated ones should be removed to maintain a current and comprehensive curriculum.

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