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The Role of the Triple Helix Model in Advancing Science, Technology and Innovation in Colleges of Education in Nigeria

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Abstract

Science, Technology, and Innovation (STI) are critical drivers of socio-economic development, yet Nigerian Colleges of Education have historically played a limited role in national innovation systems. This study examined the role of the **Triple Helix Model** and it interactions among academia, industry, and government—in advancing **STEMpreneurship and STI** in Nigerian Colleges of Education. Using a **mixed-methods design**, data were collected through **document analysis** of national policy frameworks and strategic plans, alongside **semi-structured interviews** with 30 stakeholders, including college administrators, faculty, industry partners, and government policymakers. Findings revealed that existing collaborations are often **sporadic, advisory in nature, and lack sustained co-creation**, while barriers such as **insufficient funding, weak industry linkages, bureaucratic delays, and low research capacity** hinder effective Triple Helix implementation. Stakeholders recommended strategies to enhance collaboration, including the establishment of **innovation hubs**, structured industry partnerships, policy incentives, and curriculum integration of STEMpreneurship. The study concludes that **Colleges of Education can become active contributors to Nigeria's innovation ecosystem** if institutional, industrial, and governmental synergies are strengthened. These findings have implications for policy, curriculum reform, and the promotion of applied STEM education aimed at fostering entrepreneurial and technological capacities in future educators.

Keywords: Triple Helix Model, STEMpreneurship, Science, Technology, and Innovation (STI), Colleges of Education, Nigeria, Industry–Academia–Government Collaboration

Introduction

Science, Technology, and Innovation (STI) are widely recognized as central drivers of economic growth, social transformation, and global competitiveness in the 21st century. Knowledge-based economies increasingly rely on the capacity of nations to generate, adapt, and apply scientific and technological knowledge to solve societal problems and stimulate productivity (OECD, 2015; World Bank, 2020). In developing countries such as Nigeria, STI is not only essential for industrial advancement but also for addressing pressing challenges such as unemployment, poverty, and educational quality (Arocena & Sutz, 2016). Education plays a foundational role in national innovation systems by producing the human capital required for research, technological development, and entrepreneurship. In Nigeria, tertiary institutions are expected to contribute to STI through teaching, research, and community engagement. While universities have traditionally been the focal point of STI policies and research funding, **Colleges of Education** which are primarily responsible for training teachers at the basic and secondary education levels—have received comparatively limited attention in innovation discourse (Okeke & Ebong, 2021). Yet, these institutions shape the future STEM workforce by preparing teachers who will inspire scientific curiosity, technological skills, and innovative thinking among young learners. The marginalization of Colleges of Education in national STI frameworks presents a significant gap. These institutions often emphasize pedagogy over applied research, innovation, and industry engagement, which limit their contribution to the broader innovation ecosystem (NCCE, 2019). However, as Nigeria seeks to build a technology-driven economy aligned with its development agendas, Colleges of Education must evolve from being solely teacher-training institutions to becoming **active agents of innovation, STEM capacity building, and entrepreneurship development**.

The **Triple Helix Model**, introduced by Etzkowitz and Leydesdorff (2000), provides a useful conceptual framework for understanding how innovation emerges from the dynamic interactions among **academia, industry, and government**. In this model, universities and other educational institutions are not merely knowledge transmitters but key actors in economic and technological development. Industry contributes through commercialization and market relevance, while government provides regulatory frameworks, funding, and policy direction. The strength of an innovation system depends largely on how effectively these three spheres collaborate (Etzkowitz & Zhou, 2017; Carayannis & Campbell, 2012). Applying the Triple Helix Model to Nigerian Colleges of Education suggests a shift in institutional roles: Colleges should engage more actively with industry partners in curriculum design, applied research, and innovation projects, while government must create enabling policies and funding mechanisms that support such collaborations. When these relationships are synergistic, educational institutions can contribute meaningfully to STI, not only through knowledge production but also through technology transfer, entrepreneurship, and

community problem-solving (Guerrero, Urbano, & Cunningham, 2015).

Despite its relevance, empirical research on the application of the Triple Helix Model in Nigerian Colleges of Education remains sparse. Most existing studies focus on universities, leaving a gap in understanding how teacher education institutions can participate in and benefit from innovation systems (Okeke & Ebong, 2021). This gap is particularly critical given Nigeria's urgent need to strengthen STEM education and promote entrepreneurship at all levels of the education sector. Against this backdrop, this paper examines the role of the Triple Helix Model in advancing STI in Colleges of Education in Nigeria. Specifically, it explores existing collaboration patterns among Colleges of Education, industry, and government; identifies challenges limiting effective synergy; and proposes strategies for enhancing institutional performance in science, technology, and innovation. By doing so, the study contributes to policy, practice, and scholarship on how teacher education institutions can become catalysts for sustainable development and STEM-driven transformation in Nigeria.

Conceptual Framework: The Triple Helix Model

The **Triple Helix Model** provides a powerful analytical framework for understanding how innovation emerges from the dynamic and interactive relationships among three core institutional spheres: **academia, industry, and government**. Originally articulated by Etzkowitz and Leydesdorff (2000), the model departs from linear conceptions of innovation by emphasizing **recursive, networked, and co-evolutionary processes** in which knowledge production, application, and regulation occur simultaneously. Rather than operating in isolation, the three spheres increasingly overlap in function, creating hybrid institutions, shared spaces, and collaborative mechanisms that stimulate creativity and technological advancement.

Core Actors and Their Roles

1. **Academia (Education and Research)**: serves as the primary generator of knowledge, skills, and human capital. In the Triple Helix context, higher education institutions are expected not only to teach and conduct basic research but also to engage in applied research, entrepreneurship, and technology transfer activities (Etzkowitz, 2003). For Colleges of Education, this implies moving beyond traditional teacher training toward developing research capacity in STEM education, innovation pedagogy, and educational technologies. By participating in research networks and innovation projects, Colleges of Education can contribute directly to the creation and diffusion of STEM-based solutions relevant to schools and communities.
2. **Industry (Private Sector)**: provides the commercial and practical dimension of innovation. Firms translate knowledge into products, services, and scalable technologies. In the Triple Helix Model, industry is not merely a consumer of academic outputs but an active co-producer of knowledge through joint research, internships, and curriculum co-design (Guerrero, Urbano, & Cunningham, 2015). For

Colleges of Education, partnerships with educational technology companies, engineering firms, and local enterprises enable students and staff to engage with real-world problems, thereby strengthening STEMpreneurial competencies and innovation relevance.

3. **Government (Policy and Regulation)**: acts as the enabler and orchestrator of the innovation system. It sets strategic priorities, allocates funding, and creates regulatory frameworks that either stimulate or constrain collaboration (Etzkowitz & Zhou, 2017). In Nigeria, government agencies such as the Federal Ministry of Education, the Ministry of Science and Technology, and regulatory bodies like the NCCE play crucial roles in shaping how Colleges of Education can participate in innovation ecosystems. Effective government involvement ensures policy coherence between education reform, STI development, and economic growth agendas.

Synergy and Functional Overlap

A defining feature of the Triple Helix Model is **functional overlap**, where each actor partially assumes the roles traditionally associated with the others. Universities become entrepreneurial, industries become knowledge producers, and governments become facilitators of innovation networks (Etzkowitz, 2008). This overlap leads to the creation of hybrid structures such as innovation hubs, technology parks, and incubation centers. Such spaces allow researchers, students, entrepreneurs, and policymakers to interact regularly and co-create solutions. For Colleges of Education, this functional overlap is particularly transformative. When Colleges engage in entrepreneurial activities—such as developing educational technologies, STEM kits, and community-based innovations—they redefine their institutional identity from solely teacher preparation centers to **agents of socio-economic development**. At the same time, industries that collaborate with Colleges contribute to training future teachers who are technologically competent and innovation-oriented, thus strengthening the national STEM pipeline.

Knowledge Production and Commercialization

The Triple Helix Model emphasizes the integration of **knowledge production with application and commercialization**. Innovation is not complete until ideas are translated into usable products or practices that create value (Carayannis & Campbell, 2012). In educational contexts, this may include the development of low-cost science equipment, digital learning platforms, or pedagogical tools that can be scaled across schools. In Nigeria, where resource constraints affect STEM education delivery, Colleges of Education can use Triple Helix partnerships to commercialize locally developed solutions that address educational and social needs. This aligns with the concept of the **entrepreneurial university**, which integrates teaching, research, and economic development into a unified mission (Etzkowitz, 2003).

The Triple Helix Model in Nigerian Education

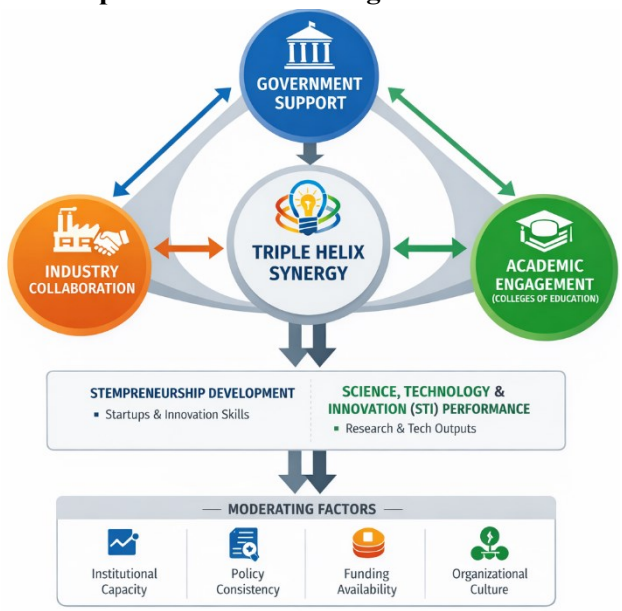


Fig.1: Triple Helix Model for Nigerian Education; Designed by Eriba and Samuel (2026)

The **Triple Helix Model**, as illustrated in the conceptual diagram, provides a framework for understanding how synergistic interactions among **Colleges of Education (Academia), Industry**, and **Government** can drive innovation and STEMpreneurship in Nigeria (Etzkowitz & Leydesdorff, 2000; Carayannis & Campbell, 2012). This model emphasizes the dynamic, overlapping roles of the three actors in co-creating knowledge, technologies, and solutions to socio-economic challenges.

Academic Engagement: Colleges of Education as Innovation Actors

In the Nigerian context, Colleges of Education have historically focused on teacher preparation, emphasizing pedagogy over applied research (NCCE, 2019). The Triple Helix framework, however, positions these institutions as active **innovation actors**, capable of contributing to science, technology, and entrepreneurship development. Academic engagement includes curriculum innovation in STEM and entrepreneurship, faculty research participation, and the establishment of innovation hubs or incubation centers (Etzkowitz, 2003; Guerrero, Urbano, & Cunningham, 2015). By participating in applied research and community-focused innovation, Colleges of Education can produce graduates equipped with both **teaching expertise and STEMpreneurial skills**, thus expanding their role beyond traditional teacher training.

Industry Collaboration: Bridging Theory and Practice

Industry serves as the practical and commercial dimension of the Triple Helix. In Nigeria, collaboration between Colleges of Education and private sector actors—such as educational technology firms, engineering companies, and local enterprises—facilitates technology transfer, joint research, and mentorship programs (Guerrero et al., 2015). Industrial engagement ensures that students acquire skills aligned with market demands, while industry gains access to academic knowledge, research outputs, and a pool of innovation-oriented graduates. Such partnerships strengthen the relevance of educational programs and support the creation of technology-based products, services, and startups (Carayannis & Campbell, 2012).

Government Support: Enabling Policy and Funding Environment

Government involvement is essential for creating a supportive ecosystem for innovation. Agencies such as the Federal Ministry of Education, the Ministry of Science and Technology, and the National Commission for Colleges of Education provide policy direction, funding, and regulatory oversight (Etzkowitz & Zhou, 2017). Government support can include innovation grants, public–private partnership facilitation, and policy incentives that encourage institutional engagement with industry and entrepreneurship. Without such enabling conditions, collaboration remains fragmented, and the full potential of innovation in Colleges of Education is limited (Arocena & Sutz, 2016).

Triple Helix Synergy: The Core of Innovation

The intersection of academia, industry, and government generates **Triple Helix Synergy**, which is the engine for effective innovation and STEMpreneurship. This synergy enables the co-creation of knowledge, shared responsibility for research outputs, and the establishment of hybrid institutions such as innovation hubs or technology incubators. In Nigeria, this model provides an opportunity for Colleges of Education to transition from teaching-only institutions to active contributors to the national innovation system (Etzkowitz, 2008; **Guerrero, Urbano, Cunningham, & Organ,** 2015).

Outcomes: STEMpreneurship and STI Performance

Effective Triple Helix interactions result in two key outcomes. First, **STEMpreneurship development**, where students gain entrepreneurial skills, innovation competence, and the ability to launch technology-based startups. Second, **Science, Technology, and Innovation (STI) performance**, characterized by increased research outputs, commercialization of innovations, and solutions that address local and national challenges (Carayannis & Campbell, 2012; Okeke & Ebong, 2021). These outcomes directly support Nigeria's socio-economic development goals, including employment generation and technological advancement.

Moderating Factors

The model also recognizes **moderating factors** such as institutional capacity, policy consistency, funding availability, and organizational culture. These factors influence the strength of interactions among Colleges, industry, and government, and determine the overall effectiveness of the innovation ecosystem. For example, limited infrastructure or insufficient funding can weaken the impact of otherwise strong partnerships (Arocena & Sutz, 2016; **Guerrero, Urbano, Cunningham, & Organ,** 2015). The diagrammatic representation of the Triple Helix Model underscores its relevance for Nigerian education. By fostering interactions among **Colleges of Education, industry, and government**, the model highlights a pathway through which teacher education institutions can contribute meaningfully to **STEMpreneurship** and broader innovation outcomes. Strengthening these interactions requires deliberate policies, sustained funding, and a culture of collaboration, ultimately transforming Colleges of Education into **drivers of technological, entrepreneurial, and**

socio-economic development. This study adopts the Triple Helix Model as its conceptual framework to examine how interactions among **Colleges of Education, industry, and government** shape the emergence of STEMpreneurship and STI outcomes in Nigeria. By analyzing the nature, intensity, and effectiveness of these interactions, the study seeks to understand how Colleges of Education can leverage collaborative networks to enhance research productivity, technology development, and entrepreneurial capacity.

The Triple Helix and Innovation

The Triple Helix Model has become a widely adopted conceptual framework for understanding how innovation emerges from the interaction of academia, industry, and government. The model posits that innovation is not linear but rather a dynamic, networked process, in which knowledge production, commercialization, and policy development occur simultaneously (Etzkowitz & Leydesdorff, 2000; Carayannis & Campbell, 2012). Research indicates that Triple Helix interactions significantly enhance national and regional innovation systems, as they facilitate knowledge exchange, collaborative research and development (R&D), and pathways for technology commercialization (Etzkowitz & Zhou, 2017). In developing countries, effective Triple Helix partnerships have been shown to strengthen the capacity of educational institutions to address local industrial and societal needs. For example, Leydesdorff and Etzkowitz (1996) argue that hybrid institutions—such as university-based incubators or government-supported innovation hubs—enable emerging economies to leverage academic knowledge for practical, market-driven applications. Similarly, **Guerrero, Urbano, Cunningham and Organ**, 2015 (2015) note that when academia, industry, and government share responsibilities for innovation, it fosters entrepreneurial mindsets, knowledge co-creation, and sustainable development outcomes. In the context of teacher education, the Triple Helix model highlights opportunities for Colleges of Education to extend their traditional roles. Beyond preparing educators, these institutions can engage in applied research, STEM curriculum innovation, and community-based entrepreneurship projects. By doing so, they contribute to the formation of a skilled workforce capable of driving STEMpreneurship and technological innovation within both the education sector and local economies (Etzkowitz, 2008; Carayannis & Campbell, 2012).

Science, Technology and Innovation (STI) in Nigerian Educational Institutions

Nigeria's higher education system has increasingly embraced the principles of Triple Helix collaboration, particularly universities that engage with industry and government in applied research, innovation centers, and startup incubators (World Bank, 2020). These institutions often develop technology-driven solutions that respond to local and national challenges, such as agricultural innovation, renewable energy solutions, and digital learning platforms. However, Colleges of Education remain largely underrepresented in national STI frameworks. Empirical studies highlight several reasons for this lag: limited research infrastructure, weak industry linkages, and inconsistent policy support (Okeke & Ebong, 2021). Furthermore,

teacher education programs often emphasize pedagogical theory over applied research or innovation projects, which constrains the potential of these institutions to produce STEM-capable entrepreneurs and innovators (NCCE, 2019). Despite these limitations, there is growing recognition that Colleges of Education can become critical contributors to national innovation systems. By engaging in joint research projects with industry, participating in government-led innovation initiatives, and integrating entrepreneurship into STEM curricula, these institutions can strengthen Nigeria's STI ecosystem and expand the reach of technological and educational innovations (Adebayo & Oladipo, 2020; Etzkowitz & Zhou, 2017).

Barriers to Triple Helix Implementation in Nigeria

The implementation of the Triple Helix Model in Nigeria's educational institutions faces several persistent challenges, particularly in Colleges of Education:

1. Insufficient Funding for Research and Innovation: Many Colleges of Education operate with limited budgets, relying on government subventions that prioritize teaching over research or innovation activities (Arocena & Sutz, 2000). This restricts the establishment of laboratories, innovation hubs, and incubation centers necessary for STEM-driven projects.
2. Weak Institutional Policies for Intellectual Property and Technology Transfer: Inadequate intellectual property frameworks and unclear technology transfer guidelines discourage industry engagement and reduce commercialization of research outputs (Etzkowitz & Zhou, 2017).
3. Low Industry Engagement: Industry often mistrusts the quality or relevance of research from Colleges of Education, or there may be mismatched expectations regarding deliverables, timelines, or commercialization potential (**Guerrero, Urbano, Cunningham & Organ**, 2015).
4. Bureaucratic Hurdles in Government Support Systems: Slow administrative procedures, inconsistent policy implementation, and fragmented government programs create obstacles for effective collaboration (Arocena & Sutz, 2000; Okeke & Ebong, 2021).

These barriers mirror broader trends in Sub-Saharan Africa, where innovation ecosystems are constrained by resource limitations, policy gaps, and weak institutional linkages (Arocena & Sutz, 2000; Etzkowitz & Leydesdorff, 2000). Overcoming these challenges requires coordinated efforts among government, industry, and academia to create enabling policies, provide sustainable funding, and foster a culture of collaboration and entrepreneurship within Colleges of Education.

Methodology

This study employed a mixed-methods research design that integrated qualitative inquiry with systematic document analysis in order to comprehensively examine the role of the Triple Helix

Model in advancing Science, Technology and Innovation (STI) and STEMpreneurship in Nigerian Colleges of Education. The choice of a mixed-methods approach was informed by its strength in enabling triangulation across multiple data sources and perspectives, thereby enhancing the depth and credibility of the findings. By combining theoretical, policy-based, and experiential evidence, the design was particularly suited to exploring complex innovation ecosystems in which universities, industry, and government interact in dynamic and context-dependent ways. The first phase of the study involved document analysis to situate the investigation within Nigeria's national education and innovation policy environment. Key documents reviewed included the National Policy on Education, Tertiary Education Trust Fund (TETFund) strategic frameworks, institutional strategic plans of selected Colleges of Education, and national Science, Technology and Innovation (STI) policy reports and white papers. These materials provided a macro-level understanding of how Colleges of Education are positioned within the national innovation system and how STEM education, research, and entrepreneurship are prioritized. The document analysis helped to identify existing policy directions, institutional strategies, and gaps in Triple Helix engagement. Data from the documents were analyzed thematically to extract recurring patterns, policy alignments, and evidence of collaborative initiatives, which in turn informed the development of the interview protocols.

To generate micro-level and context-specific insights, semi-structured interviews were conducted with 30 key stakeholders drawn from all three spheres of the Triple Helix. These included:

i. College administrators (n=8) responsible for academic and research planning, curriculum development, and innovation initiatives.
ii. School members (n=10) involved in STEM teaching, research, and student entrepreneurship mentoring.
iii. Industry representatives (n=6) from technology, engineering, and educational service companies collaborating with Colleges of Education.
iv. Government policymakers (n=6) from relevant ministries and agencies overseeing education, science, and innovation programs.

Participants were selected using purposive sampling to ensure that those with direct experience in partnership development, innovation practices, and policy implementation were included. The semi-structured format allowed participants to articulate nuanced views on collaboration processes, institutional challenges, and opportunities for strengthening STI and STEMpreneurship in Colleges of Education. Interview questions explored the nature and scope of existing partnerships among Colleges, industry, and government; perceived barriers to effective Triple Helix engagement; strategies for promoting innovation and STEM-based entrepreneurship; and the policy and institutional factors shaping collaboration outcomes. All interviews were conducted with informed consent, audio-recorded, and transcribed verbatim. The transcripts were analyzed thematically using NVivo software. Codes were developed

around the core research constructs of academic engagement, industry collaboration, government support, synergy, STEMpreneurship outcomes, and implementation barriers. The themes emerging from the interviews were cross-validated with findings from the document analysis to ensure methodological triangulation, enhance data credibility, and strengthen the overall trustworthiness of the study.

Data Presentation and Analysis

This chapter presents the findings from the study on the role of the Triple Helix Model in advancing STEMpreneurship and STI in Nigerian Colleges of Education. Data were drawn from document analysis and semi-structured interviews with 30 stakeholders across the three Triple Helix actors: academia, industry, and government. Findings are organized under key thematic areas: (i) existing collaborations, (ii) STI and STEMpreneurship outcomes, (iii) challenges to Triple Helix implementation, and (iv) strategies for enhancing partnerships.

Theme 1: Existing Collaborations Among Triple Helix Actors

The findings under this theme indicate that existing collaborations among Triple Helix actors in Nigeria are unevenly distributed, with Colleges of Education occupying a relatively marginal position in national innovation networks. Document analysis showed that while universities are increasingly embedded in formal partnerships with industry and government—particularly in areas of research, technology development, and commercialization—Colleges of Education tend to maintain only limited and largely instructional-oriented linkages. Their strategic plans emphasize partnerships mainly for teaching practice placements, curriculum alignment, and staff development, rather than for applied STEM research, product development, or innovation hub participation. This pattern was reinforced by the interview data, which revealed that collaboration between Colleges of Education and industry is often ad hoc and weakly institutionalized. From the academic perspective, partnerships were described as fragmented and peripheral to core research and innovation functions. One faculty member noted that although some internship agreements exist with technology companies, these arrangements are sporadic and rarely integrated into broader research or innovation projects. As a result, students and staff are exposed to industry environments without being actively engaged in problem-solving, prototyping, or technology-driven inquiry. Industry stakeholders similarly acknowledged the limited depth of their engagement with Colleges of Education. An EdTech company representative explained that collaboration is mostly advisory in nature, focusing on consultation and occasional training support rather than joint development of educational technologies or STEM solutions. This suggests that Colleges of Education are often viewed as consumers of industry expertise rather than co-creators of innovation. Taken together, these findings highlight a structural gap in the Triple Helix ecosystem as it relates to teacher education institutions in Nigeria. While Colleges of Education play a critical role in human capital formation, their potential contribution to applied STEM research and innovation remains underutilized. The absence of strong,

formalized collaboration mechanisms constrains their ability to participate meaningfully in knowledge production, technology transfer, and entrepreneurial activity. Strengthening institutional frameworks for partnership, embedding innovation goals into college mandates, and repositioning Colleges of Education as active actors in the national innovation system are therefore essential for realizing the full promise of the Triple Helix Model in Nigeria.

Theme 2: STI and STEMpreneurship Outcomes

The findings under this theme underscore the latent but largely underexploited capacity of Colleges of Education in Nigeria to contribute meaningfully to Science, Technology, and Innovation (STI) and STEMpreneurship. Stakeholders across the Triple Helix spheres emphasized that, given their role in training future science and technology teachers, these institutions are strategically positioned to stimulate innovation at both the pedagogical and applied levels. Through curriculum-driven STEM initiatives, student-led innovation projects, and practice-oriented research, Colleges of Education can serve as incubators for entrepreneurial mindsets and problem-solving competencies. From the academic perspective, faculty members highlighted that students who participated in pilot innovation projects—such as the design and development of low-cost science kits and locally adaptable teaching tools—demonstrated notable growth in creativity, technical skills, and entrepreneurial orientation. These initiatives encouraged students to identify contextual educational problems, develop functional prototypes, and explore basic market viability. As a result, STEMpreneurship was not only framed as a business activity but also as a socially responsive process aimed at improving science learning outcomes in resource-constrained environments.

Despite these promising developments, stakeholders also noted that the broader STI impact of Colleges of Education remains limited due to weak commercialization and innovation diffusion mechanisms. Government officials acknowledged that although research and innovation outputs exist in the form of instructional technologies, learning tools, and small-scale prototypes, there are few institutional structures to support patenting, licensing, or startup incubation. Consequently, innovations often remain at the demonstration stage without transitioning into scalable products or services that could contribute to national development goals. This gap between innovation potential and market or policy impact reflects a broader systemic weakness within the STI ecosystem of Colleges of Education. Without technology transfer offices, innovation hubs, or formal industry linkage platforms, promising ideas fail to progress beyond academic settings. Strengthening pathways for intellectual property protection, startup support, and public–private co-development would therefore be critical to unlocking the full STEMpreneurial capacity of these institutions. In this regard, Colleges of Education can move from being passive training centers to becoming active contributors to Nigeria's innovation economy through structured Triple Helix engagement.

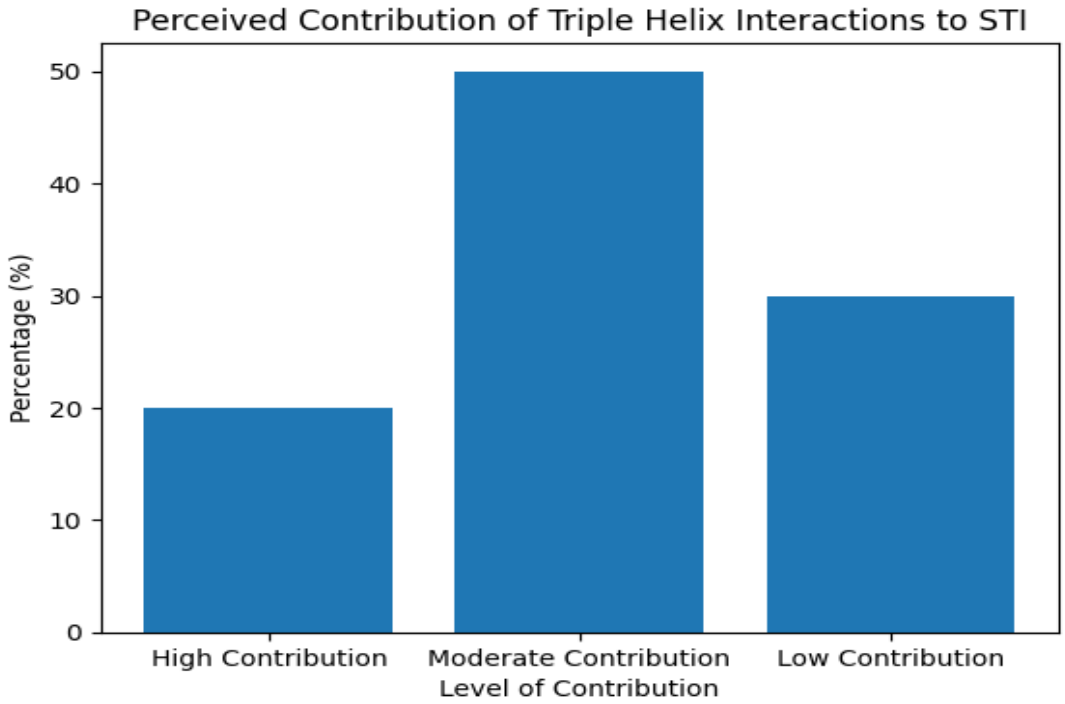


Fig. 1: Perceived Contribution of Triple Helix Collaboration to STI Outcomes

The graph illustrates stakeholders' perceptions of how effectively Triple Helix interactions (academia–industry–government collaboration) contribute to Science, Technology, and Innovation (STI) in Nigerian Colleges of Education. Three levels of contribution are represented: high (20%), moderate (50%), and low (30%). The dominance of the *moderate contribution* category (50%) indicates that most stakeholders recognize the presence of some level of collaboration among Colleges of Education, industry, and government. However, this collaboration is perceived as partial and inconsistent rather than fully institutionalized or impactful. This suggests that while linkages exist, they are not yet strong enough to drive robust research output, commercialization, or large-scale innovation. The *low contribution* response (30%) is also significant and signals persistent structural and operational challenges. These may include weak research infrastructure, limited funding, and absence of innovation hubs, poor technology transfer mechanisms, and fragile industry trust in Colleges of Education as innovation partners. This group reflects stakeholders who experience minimal practical benefits from existing partnerships. Only 20% of respondents perceive Triple Helix interactions as making a *high contribution* to STI. This small proportion likely represents Colleges or regions where structured partnerships, active research programs, and supportive government policies are already in place. However, the low size of this group highlights that such success stories are still exceptions rather than the norm.

Overall, the graph suggests that Nigeria's Colleges of Education are positioned in a transitional stage of the innovation ecosystem. The system has moved beyond complete isolation but has

not yet achieved strong synergy among the three helix actors. The predominance of moderate and low ratings underscores the need for deliberate policy reforms, stronger Directorate of Research and Development (DRD) leadership, improved funding strategies, and institutional frameworks for innovation and commercialization. While Triple Helix interactions are acknowledged as relevant, their current impact on STI in Colleges of Education is not yet transformative. For these institutions to become active contributors to Nigeria's innovation economy, collaboration must evolve from informal and fragmented engagements into structured, outcome-driven, and sustainable partnerships.

Theme 3: Barriers to Triple Helix Implementation

The findings under this theme reveal that the implementation of the Triple Helix Model in Nigerian Colleges of Education is constrained by a set of interrelated structural, institutional, and human capacity challenges. In line with earlier studies on innovation systems in developing contexts, stakeholders consistently pointed to inadequate funding as a major impediment to effective collaboration and innovation. Limited institutional budgets restrict the acquisition of modern laboratory equipment, the establishment of functional innovation hubs, and the provision of internal research grants. Without reliable financial support, Colleges of Education struggle to move beyond basic instructional functions into research-intensive and innovation-driven activities. Another critical barrier identified is the weakness of linkages between Colleges of Education and industry. Stakeholders described a relationship characterized by mutual mistrust and misaligned expectations. From the industry perspective, Colleges are often perceived as lacking the technical depth or research orientation required for product development and commercialization. Conversely, academic staff view industry partners as overly profit-driven and insufficiently committed to long-term capacity building. This disconnect reduces the likelihood of co-developed projects, limits knowledge exchange, and weakens the overall synergy expected within the Triple Helix framework.

Policy and bureaucratic constraints also emerged as significant obstacles to effective collaboration. Government officials and academic leaders noted that innovation-related projects frequently encounter delays due to lengthy approval processes, rigid administrative procedures, and unclear regulatory pathways. Such inefficiencies discourage initiative-taking and slow down the implementation of research and development activities. In an environment where innovation thrives on speed, flexibility, and experimentation, excessive bureaucracy undermines institutional responsiveness and weakens the motivation of both staff and external partners. In addition to financial and structural barriers, low research and entrepreneurial capacity among faculty members further constrains Triple Helix implementation. Many academic staff in Colleges of Education are trained primarily in pedagogical theory and classroom instruction, with limited exposure to applied research methods, technology development, or entrepreneurship. As a result, they often lack the skills needed to initiate industry-relevant research, secure competitive grants, or mentor students in STEM-based venture creation. This skills gap reduces the ability of Colleges to function as active innovation

nodes within the national system. Taken together, these barriers demonstrate that the challenge is not merely one of policy intent but of institutional readiness and systemic support. For the Triple Helix Model to be effectively operationalized in Nigerian Colleges of Education, there must be deliberate investments in funding, partnership structures, policy reform, and human capital development. Addressing these constraints is essential if Colleges of Education are to transition from being peripheral actors to becoming central contributors to Nigeria's STI and STEMpreneurship agenda.

Theme 4: Strategies for Enhancing Partnerships

Stakeholders suggested several strategies to strengthen Triple Helix interactions:

1. Institutional Capacity Building: Establish innovation labs, STEM incubators, and research centers in Colleges of Education.
2. Policy Incentives: Government to provide grants, tax incentives, and streamlined approval processes for collaborative projects.
3. Industry Engagement Mechanisms: Develop MOUs for co-research, internships, mentorship, and technology transfer.
4. Curriculum Integration: Embed entrepreneurship and applied STEM projects into teacher education programs.
5. Monitoring and Evaluation: Implement systematic assessment of partnerships and innovation outcomes.

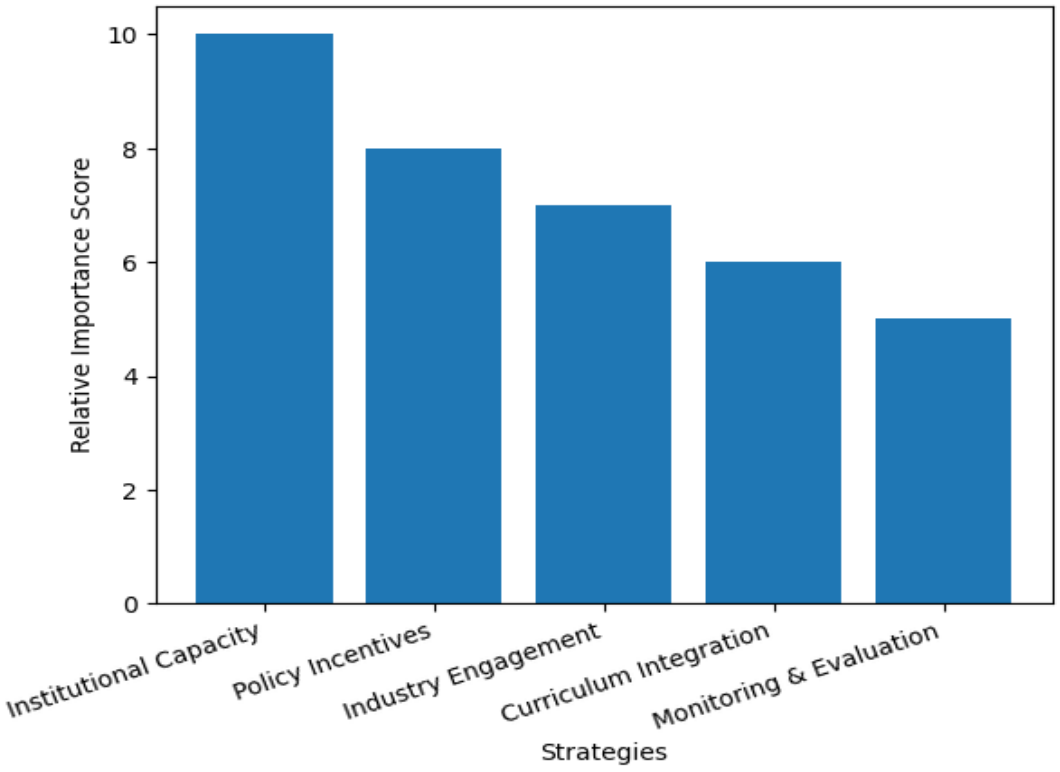


Fig. 2: Recommended Strategies for Effective Triple Helix Collaboration

The data on recommended strategies for strengthening collaboration among academia, industry, and government show that building institutional capacity is perceived as the most critical factor for improving innovation outcomes in Nigerian Colleges of Education. Stakeholders emphasized that without strong internal systems—such as functional research units, innovation hubs, skilled personnel, and effective leadership structures—meaningful collaboration cannot be sustained. Institutional capacity therefore serves as the foundation upon which all other Triple Helix activities depend. Closely following this is the importance of policy incentives, which highlights the central role of government in enabling innovation through supportive regulations, funding schemes, and targeted programs. Respondents indicated that when policies are clear, consistent, and innovation-friendly, both academic institutions and industry actors are more motivated to engage in long-term partnerships. Policy incentives help reduce risk, encourage investment in research, and legitimize collaboration as a national priority.

Industry engagement was also ranked highly, reflecting the need for deeper and more practical relationships with the private sector. Stakeholders stressed that collaboration should go beyond advisory roles to include joint research, co-development of educational technologies, student innovation projects, and commercialization initiatives. Strong industry engagement ensures that research outputs are relevant to real-world needs and aligned with market demands. The emphasis on curriculum integration shows that collaboration and innovation must be embedded within teaching and learning processes. By integrating STEMpreneurship, applied research, and problem-based learning into teacher education programs, Colleges of Education can produce graduates who are not only effective educators but also innovators and change agents within the education and technology sectors. Finally, monitoring and evaluation, although ranked lower than other strategies—remains essential for sustaining collaboration over time. Stakeholders noted that systematic assessment of partnerships, research outputs, and innovation impacts is necessary for accountability, learning, and continuous improvement. Overall, the findings suggest that improving Triple Helix collaboration in Nigerian Colleges of Education requires a systems-driven approach, beginning with strong institutional capacity, reinforced by enabling policies, active industry participation, curriculum reform, and continuous evaluation. These elements together create the conditions for sustainable STI and STEMpreneurship development.

The findings indicate that while Colleges of Education in Nigeria have potential to contribute to STI and STEMpreneurship, current Triple Helix collaborations are limited, sporadic, and underfunded. Stakeholders agree that enhanced institutional capacity, policy support, and structured industry engagement are essential for transforming these colleges into innovation hubs. The study also confirms that funding, weak industry linkages, and bureaucratic hurdles remain significant barriers, echoing findings from prior studies (Arocena & Sutz, 2000; Okeke & Ebong, 2021; Etzkowitz & Zhou, 2017).

Discussion of Findings

The findings of this study were interpreted within the framework of the Triple Helix Model and existing literature, with particular attention to the role of Colleges of Education in promoting Science, Technology and Innovation (STI) and STEMpreneurship in Nigeria. The evidence shows that, although Nigerian universities have increasingly engaged in collaborative research and innovation with industry and government, Colleges of Education remain largely underutilized in national STI initiatives. Both the document analysis and interview data revealed that partnerships involving Colleges of Education are often sporadic, informal, and limited to internships, curriculum advice, or short-term training support. They rarely extend to co-creative research projects, product development, or technology commercialization. This pattern supports earlier findings by Okeke and Ebong (2021), who observed that Colleges of Education tend to prioritize pedagogical training over applied research, thereby constraining their participation in innovation ecosystems. From a Triple Helix perspective, this suggests that while Colleges possess knowledge and human capital, the synergistic potential of collaboration with industry and government remains largely unrealized (Etzkowitz & Leydesdorff, 2000). Despite these limitations, stakeholders emphasized that Colleges of Education have considerable untapped potential to contribute to STI and STEMpreneurship through applied research, innovation hubs, and student-led startups. Faculty and industry participants cited examples of pilot initiatives, such as the development of low-cost science kits and mobile learning applications, which demonstrated students' growing innovation skills and entrepreneurial orientation. However, the overall impact of these efforts remains moderate, largely due to weak institutional infrastructure, limited funding, and the absence of systematic commercialization pathways. This finding is consistent with Carayannis and Campbell's (2012) argument that innovation depends on strong Triple Helix synergy that converts academic knowledge into socially and economically valuable outputs. Strengthening collaboration among academia, industry, and government can therefore enhance STEM skills development, entrepreneurial capacity, and innovation performance, helping to address Nigeria's persistent challenges of graduate unemployment and low industrial productivity.

The study also identified several barriers that limit the effective implementation of the Triple Helix Model in Nigerian Colleges of Education. These include insufficient funding for research and innovation, weak industry linkages characterized by mistrust and misaligned expectations, policy and bureaucratic hurdles that slow government support, and low research and entrepreneurial capacity among faculty members. These challenges are consistent with earlier studies in Sub-Saharan Africa, which emphasize that structural and institutional weaknesses reduce the effectiveness of innovation systems (Arocena & Sutz, 2000; Guerrero et al., 2015; Etzkowitz & Zhou, 2017). In particular, limited industry engagement and inadequate government responsiveness restrict the commercialization of innovations and weaken the development of STEMpreneurial ecosystems. This suggests that the mere presence of the three Triple Helix actors is insufficient; what matters is the quality, intensity, and

sustainability of their interactions. In response to these constraints, stakeholders proposed strategies that align closely with the principles of the Triple Helix Model. These include building institutional capacity through the establishment of STEM innovation hubs and entrepreneurship centers, introducing policy incentives such as grants and streamlined approval processes, formalizing industry engagement through memoranda of understanding for joint research and mentorship, integrating entrepreneurship and innovation projects into STEM teacher education curricula, and strengthening monitoring and evaluation systems. Together, these strategies promote co-creation of knowledge, technology development, and entrepreneurial opportunities, reinforcing Etzkowitz's (2008) view that innovation emerges from interactive and overlapping networks rather than linear processes.

Overall, the findings demonstrate that the Triple Helix framework provides a useful lens for understanding STI and STEMpreneurship in Nigerian Colleges of Education. Colleges possess the human capital and pedagogical expertise needed for innovation but require stronger research and entrepreneurial capabilities. Industry offers practical relevance, mentorship, and commercialization channels but needs clearer mechanisms for engagement. Government plays a critical enabling role through policy and funding but must address bureaucratic inefficiencies to strengthen the innovation ecosystem. When these actors interact effectively, they generate synergy that leads to STEMpreneurship development and measurable STI outputs, supporting Etzkowitz and Zhou's (2017) assertion that innovation arises from co-evolving institutional relationships. The study therefore makes an important contribution to policy and practice. It suggests that Colleges of Education should emphasize applied research, establish innovation centers, and integrate entrepreneurship into STEM curricula. Industry should engage more deeply in research partnerships, mentoring programs, and technology transfer initiatives. Government should provide consistent funding, streamline regulatory procedures, and implement policies that incentivize collaborative innovation. By adopting these measures, Colleges of Education can become active participants in Nigeria's national innovation system, producing graduates capable of addressing socio-economic challenges through STEMpreneurship. While Nigerian Colleges of Education possess significant potential for STI and STEMpreneurship, their current engagement with Triple Helix actors remains limited and fragmented. Effective collaboration requires deliberate institutional reforms, stronger industry involvement, and supportive government policies. When these conditions are met, Colleges of Education can be transformed into centers of innovation, contributing to sustainable economic growth and technological advancement in Nigeria.

Conclusion

This study examined the role of the Triple Helix Model in advancing Science, Technology and Innovation (STI) and STEMpreneurship in Nigerian Colleges of Education. The findings show that although these institutions possess significant potential to contribute to national innovation systems, their current engagement with industry and government remains limited, fragmented, and inadequately funded. As a result, their role in Nigeria's STI agenda is still

largely peripheral rather than transformative. The evidence indicates that existing collaborations involving Colleges of Education are often sporadic and advisory in nature, with few sustained initiatives focused on co-creation, product development, or commercialization. While partnerships exist, they rarely translate into structured research projects or innovation ventures that could generate scalable technological or entrepreneurial outcomes. At the same time, the study confirms that Colleges of Education have considerable untapped capacity for applied research and innovation, particularly in the areas of STEM education, instructional technologies, and student entrepreneurship. However, several barriers continue to constrain effective implementation of the Triple Helix Model. These include insufficient funding for research and innovation activities, weak and mistrustful industry linkages, bureaucratic delays in government processes, and low institutional research and entrepreneurial capacity. Together, these factors limit the ability of Colleges of Education to function as active innovation nodes within Nigeria's broader knowledge economy.

Stakeholders strongly emphasized that improving institutional capacity, introducing supportive policy incentives, strengthening structured industry engagement, integrating entrepreneurship into STEM curricula, and establishing robust monitoring and evaluation systems are critical strategies for enhancing STI and STEMpreneurship outcomes. These measures are necessary to move collaboration from informal and fragmented interactions to sustained, outcome-driven partnerships. Overall, the study demonstrates that the Triple Helix Model provides a viable and contextually relevant framework for repositioning Nigerian Colleges of Education as active contributors to innovation ecosystems. By fostering synergy among academia, industry, and government, these institutions can move beyond traditional teacher education roles and emerge as engines of technological development, entrepreneurship, and socio-economic growth. When properly supported, Colleges of Education can play a strategic role in preparing not only teachers, but also innovators and problem-solvers capable of addressing Nigeria's development challenges.

Recommendations

Based on the findings, the following are the recommendations:

1. **Establish Innovation Ecosystems:** Colleges of Education, in collaboration with industry and government, should create dedicated innovation hubs and incubators. These spaces would support STEM research, prototyping, student-led startups, and applied entrepreneurial projects, ensuring that academic knowledge is translated into practical and marketable innovations.
2. **Enhance Human and Institutional Capacity:** School and administrative staff should receive continuous training in applied research, entrepreneurship, technology commercialization, and project management. Industry partners can contribute mentorship and technical guidance, while government agencies provide funding and supportive policies to build institutional readiness for innovation.

3. **Integrate STEMpreneurship into Curriculum and Practice:** Teacher education programs should embed practical innovation projects, entrepreneurship skills, and industry collaboration into the curriculum. Industry input should guide the development of market-relevant competencies, and government frameworks should incentivize the adoption of such curriculum reforms through grants and recognition programs.
4. **Strengthen Structured Industry Collaboration:** Industry and Colleges of Education should formalize partnerships through memoranda of understanding for co-research, product development, mentorship, and technology transfer initiatives. Government support in the form of streamlined regulatory processes and policy incentives can ensure these collaborations are sustainable and impactful.
5. **Implement Policy and Funding Support:** Government agencies should provide consistent research grants, tax reliefs, and simplified approval procedures to facilitate collaborative innovation projects. Simultaneously, all Triple Helix actors must ensure that funding, resources, and institutional priorities are aligned to support applied research and entrepreneurship initiatives.
6. **Monitor, Evaluate, and Learn:** A joint monitoring and evaluation mechanism should be established across academia, industry, and government to assess the effectiveness, efficiency, and impact of collaborative projects. This would ensure accountability, inform continuous improvement, and highlight best practices in STI and STEMpreneurship development.
7. **Foster a Collaborative Culture and Technology Use:** Regular stakeholder forums, workshops, joint innovation summits, and digital platforms for knowledge sharing and project management should be adopted to nurture trust, strengthen networks, and facilitate continuous engagement among all Triple Helix actors.

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