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# Gender, Knowledge, and Innovation in Africa: A Qualitative Analysis of Science, Technology, and Stem Dynamics

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## Abstract

The intersection of science, technology, and gender has become a critical concern in contemporary development discourse, particularly within African contexts characterized by historical inequalities, colonial legacies, and uneven innovation systems. This qualitative study interrogates how gender operates as a structural force shaping scientific knowledge production, technological design, and innovation governance in Africa. Drawing on feminist epistemologies, social construction of technology (SCOT), and political economy perspectives, the article synthesises conceptual, theoretical, and empirical literature to examine persistent gender biases in science and technology systems. Thematic analysis reveals entrenched gender exclusions in scientific narratives, masculinised innovation spaces, unequal participation in STEM, digital divides, and weak gender mainstreaming in STI policies. The study argues that without transformative, gender-responsive approaches to science, technology, and innovation (STI), African development strategies risk reproducing existing social inequalities. The article concludes by proposing policy-oriented recommendations aimed at institutional reform, inclusive innovation, and gender-equitable knowledge economies.

**Keywords:** *Gender, Science and Technology, Innovation Systems, Feminist Epistemology, STI Policy*

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## Background to the Study

Science, technology, and innovation (STI) are widely recognised as central drivers of economic growth, social transformation, and sustainable development. In Africa, STI is increasingly positioned as a pathway for addressing structural challenges such as poverty, food insecurity, public health crises, and environmental degradation. However, the benefits of scientific advancement and technological innovation are not evenly distributed across social groups, particularly along gender lines. Gender inequalities remain deeply embedded in the structures, practices, and cultures of scientific institutions and innovation systems.

Existing scholarship demonstrates that science and technology are not neutral or value-free domains but are socially constructed and shaped by power relations, including gender, class, race, and colonial histories (Harding, 1991; Wajcman, 2004). Feminist scholars have long argued that dominant scientific paradigms privilege masculinised forms of knowledge while marginalising women's contributions, experiences, and epistemologies (Haraway, 1988). In African contexts, these gendered dynamics intersect with postcolonial conditions, weak institutional capacities, and informal innovation systems that are often overlooked in mainstream STI policy frameworks.

Despite growing policy attention to gender mainstreaming in STI at global and regional levels, empirical evidence suggests that women remain underrepresented in STEM education, research careers, and innovation leadership across Africa (UNESCO, 2021). Moreover, technological design processes frequently ignore women's needs, resulting in innovations that reinforce gendered labour divisions and social inequalities. This study therefore seeks to provide a holistic qualitative analysis of the gendered nature of science, technology, and innovation in Africa by integrating conceptual, theoretical, and empirical perspectives.

## Objectives of the Study

The main objective of this study is to examine the gendered dynamics of science, technology, and innovation within African contexts. The specific objectives are to:

1. Analyse key conceptual and theoretical frameworks linking gender, science, and technology.
2. Examine historical and contemporary gender exclusions in scientific knowledge production.
3. Explore gender biases embedded in technological design and innovation systems.
4. Assess gender inequalities in STEM education, digital technologies, and emerging innovations.
5. Evaluate the effectiveness of gender mainstreaming strategies in STI policy and governance.
6. Propose policy recommendations for promoting gender equity in African STI systems.

## Methodology

This study adopts a qualitative research design based on systematic literature analysis and thematic synthesis. Data were drawn from peer-reviewed journal articles, policy reports, books, and institutional publications produced by organisations such as UNESCO, the African Union (AU), and national STI agencies. Sources were selected based on relevance to gender, science, technology, and development, with particular attention to African contexts. The analysis followed a thematic approach, enabling the identification, interpretation, and organisation of recurring patterns across the literature (Braun & Clarke, 2006). Themes were derived deductively from the course framework and inductively from the reviewed texts. This qualitative approach allows for an in-depth understanding of complex social processes shaping gender relations within STI systems.

## Literature Review

### Conceptual Literature

#### *Gender*

Gender is not simply a biological distinction between males and females but a socially constructed system of meanings, roles, and power relations that structures social life. As Connell (2009) argues, gender operates as a fundamental social structure that shapes identities, institutional arrangements, and patterns of resource allocation across societies. Within this framework, gender determines who is recognised as a legitimate knowledge producer, whose expertise is valued, and who gains access to education, professional networks, and decision-making spaces.

Gender relations are reproduced through social institutions such as the family, education systems, labour markets, and the state, all of which play a crucial role in shaping participation in science and technology. In scientific and technological fields, gender norms have historically privileged masculinised traits such as objectivity, competitiveness, and technical rationality, while devaluing forms of knowledge associated with care, collaboration, and embodiment—qualities often socially ascribed to women. As a result, women's contributions to scientific knowledge and technological innovation have frequently been marginalised or rendered invisible.

The concept of intersectionality further deepens the analysis of gender by recognising that gender does not operate in isolation but intersects with other axes of social differentiation such as class, ethnicity, age, disability, and geographical location (Crenshaw, 1989). In scientific and technological spaces, these intersecting identities produce uneven experiences of inclusion and exclusion. For instance, the barriers faced by an urban, middle-class woman in STEM may differ significantly from those encountered by a rural woman engaging in informal or indigenous innovation systems. Intersectionality therefore challenges homogenised representations of "women in science" and underscores the need for context-specific and socially grounded analyses of gender inequalities.

In African contexts, gender relations in science and technology are further shaped by historical legacies of colonialism, patriarchy, and uneven development. Colonial education systems systematically restricted women's access to formal scientific training, reinforcing gendered hierarchies of knowledge that persist in contemporary STI institutions.

Consequently, understanding gender as a social structure provides a critical lens for interrogating how power, exclusion, and inequality are embedded in scientific and technological practices.

***Science, Technology, and Innovation***

Science, technology, and innovation (STI) refer to interconnected processes of knowledge production, technological development, application, and diffusion that drive socio-economic transformation. Science involves systematic inquiry aimed at generating knowledge, technology translates knowledge into practical tools and systems, while innovation encompasses the social and institutional processes through which new or improved ideas are adopted and scaled. Importantly, these processes are not autonomous or value-neutral; they are deeply embedded within social, political, and cultural institutions.

From a gender perspective, STI systems reflect prevailing social norms and power relations, often privileging male-dominated actors, disciplines, and forms of expertise. Schiebinger (2014) contends that when gender is ignored in scientific research and technological design, innovation processes tend to reproduce existing inequalities rather than challenge them. For example, research agendas may prioritise issues aligned with male interests, while technologies may be designed without consideration of women's needs, labour burdens, or lived experiences. STI institutions, including universities, research centres, innovation hubs, and policy agencies, are themselves gendered organisations. Recruitment practices, career progression pathways, funding allocation, and evaluation criteria frequently disadvantage women and other marginalised groups. These institutional biases contribute to persistent gender gaps in STEM education, research leadership, patenting, and entrepreneurial activity, particularly in low- and middle-income contexts.

Moreover, dominant models of STI often overlook informal innovation and indigenous knowledge systems, where women play significant roles, especially in agriculture, health, and environmental management. The exclusion of these knowledge forms from formal innovation systems reflects narrow definitions of science and technology that privilege Western, masculinised epistemologies. A gender-responsive STI framework therefore calls for a broader understanding of innovation, one that recognises diverse knowledge systems and values inclusivity, social relevance, and ethical responsibility. Transforming STI systems requires deliberate interventions that integrate gender analysis into research design, technological development, and policy formulation. Gender-responsive science and innovation not only promote equity but also enhance the quality, relevance, and societal impact of knowledge production. By addressing gender biases within STI, societies can unlock a wider range of talents, perspectives, and solutions necessary for sustainable and inclusive development.

***Science, Technology, Engineering, and Mathematics (STEM)***

STEM—an acronym for Science, Technology, Engineering, and Mathematics, represents an integrated field of knowledge and practice that underpins contemporary scientific advancement, technological innovation, and economic development. Conceptually, STEM extends beyond a collection of technical disciplines to constitute a strategic knowledge domain through which societies produce, apply, and govern scientific and technological expertise. As such, STEM functions both as an educational framework and as a socio-institutional system embedded within broader political, economic, and cultural contexts. From a conceptual standpoint, STEM is often framed as a neutral and meritocratic space driven by objective knowledge, technical competence, and innovation efficiency. However, critical scholarship challenges this assumption, arguing that STEM disciplines are socially constructed and shaped by historical power relations, including gender, class, and race (Harding, 1991; Wajcman, 2004). The organisation of STEM education, research priorities, and professional cultures reflects dominant social norms that influence who participate, whose knowledge is legitimised, and which problems are deemed worthy of scientific attention.

STEM operates as a key mechanism for human capital formation within national and global knowledge economies. Governments and development agencies increasingly promote STEM education as essential for competitiveness, industrialisation, and participation in the Fourth Industrial Revolution. Yet, the conceptualisation of STEM as a driver of growth often prioritises economic productivity over social inclusion, thereby obscuring persistent inequalities in access, participation, and outcomes. This growth-oriented framing tends to marginalise gender analysis and overlooks the uneven distribution of opportunities within STEM systems.

Conceptually, STEM also embodies a gendered division of knowledge and labour. Scientific and technical expertise has historically been associated with masculinity, rationality, and abstraction, while social, care-oriented, and contextual knowledge has been feminised and devalued. These symbolic associations shape educational trajectories, occupational choices, and institutional cultures within STEM fields. Consequently, women and other marginalised groups frequently encounter structural and cultural barriers, including gender stereotypes, exclusionary pedagogies, and discriminatory professional practices.

In African contexts, the conceptual framing of STEM is further influenced by colonial legacies and postcolonial development agendas. Colonial education systems prioritised technical training aligned with extractive and administrative needs, while systematically excluding women and indigenous knowledge systems. Contemporary STEM policies often replicate these exclusions by privileging formal, Western scientific paradigms and neglecting informal innovation and locally grounded technological practices where women are actively involved. A gender-responsive conceptualisation of STEM therefore calls for a redefinition of scientific and technical excellence that values diversity, inclusivity, and social relevance. This involves recognising STEM not only as a technical enterprise but as a social institution shaped by power relations and ethical considerations. Integrating gender perspectives into STEM conceptual frameworks enhances the transformative potential of science and technology by aligning innovation with broader goals of equity, sustainability, and human development.

**Table 1 :** Conceptual Differences and Relationships between Gender, STI, and STEM

| Concept | Core Meaning | Primary Focus | Key Actors / Domains | Relationship to Other Concepts |
|---|---|---|---|---|
| Gender | A socially constructed system of roles, identities, norms, and power relations that shape access to resources, opportunities, and decision-making | Power, inequality, social relations, and identity formation | Individuals, households, institutions, states, and cultural systems | Gender cuts across and structures participation in both STI and STEM, influencing who produces knowledge, whose knowledge is valued, and who benefits from scientific and technological processes |
| Science, Technology and Innovation (STI) | Interconnected processes of knowledge production, technological development, application, diffusion, and governance | Societal problem-solving, economic development, and innovation systems | Research institutions, governments, industries, policy frameworks, and innovation ecosystems | STI provides the broader institutional and policy environment within which STEM operates; gender shapes STI priorities, governance, and outcomes |
| STEM (Science, Technology, Engineering and Mathematics) | A cluster of academic disciplines and professional fields focused on scientific inquiry, technical problem-solving, and quantitative analysis | Education, skills development, research careers, and technical labour markets | Schools, universities, laboratories, engineers, scientists, and technologists | STEM constitutes the human capital and disciplinary base of STI; gender influences access to STEM education, career progression, and professional recognition |
| Gender and STI | Analysis of how gender relations shape innovation systems and policy outcomes | Inclusion, equity, and social relevance of innovation | Policymakers, researchers, innovators, civil society | Gender-responsive STI enhances innovation quality, relevance, and developmental impact |
| Gender and STEM | Examination of gender disparities in STEM education and careers | Participation, representation, and retention | Students, academics, professionals, institutions | Addressing gender inequalities in STEM strengthens STI systems and knowledge economies |
| STI–STEM Nexus | The dynamic interaction between disciplinary knowledge (STEM) and innovation systems (STI) | Knowledge translation, skills utilisation, and economic transformation | Education systems, innovation hubs, labour markets | STEM supplies skilled actors to STI, while STI policies shape the demand, direction, and value of STEM knowledge |

Conceptually, gender functions as a cross-cutting social structure that shapes power relations and access within both STEM and STI. STEM represents the disciplinary and human capital foundation of scientific and technological activity, focusing primarily on education, skills, and professional practice. STI, by contrast, constitutes the broader institutional, policy, and innovation ecosystem that governs how scientific knowledge and technologies are produced, applied, and diffused within society. The relationship between the three is therefore mutually reinforcing: gender structures participation and outcomes in STEM; STEM supplies expertise and skills to STI systems; and STI frameworks shape the direction, inclusivity, and societal impact of STEM knowledge.

**Theoretical Literature**

The analysis of gender in science, technology, and innovation (STI) draws on multiple theoretical frameworks that illuminate how knowledge, technologies, and innovation systems are socially constructed, historically situated, and power laden. These frameworks—feminist epistemology, the Social Construction of Technology (SCOT), and political economy/postcolonial theory, provide complementary lenses for understanding gendered patterns of exclusion and inclusion in STI.

**1. Feminist Epistemology**

Feminist epistemology challenges the dominant assumption that science is objective, value-free, and universally applicable. Scholars such as Haraway (1988) argue that all knowledge is socially situated, shaped by the positionality, values, and experiences of its producers. From this perspective, traditional scientific methods often reflect male-dominated worldviews, marginalising perspectives that emerge from women lived experiences.

In the context of Nigeria and West Africa, feminist epistemology provides a lens to examine how colonial and postcolonial scientific systems systematically excluded women and indigenous knowledge. Empirical research in agricultural and health sciences demonstrates that women's experiential knowledge, such as seed selection, herbal medicine, and community-based problem-solving, has been undervalued in formal research agendas (Odora Hoppers, 2004; Mama, 2003). Feminist epistemology thus calls for integrating women's standpoints into STI knowledge production, ensuring that research questions, methodologies, and outcomes reflect diverse social realities.

**2. Social Construction of Technology (SCOT)**

The SCOT framework, developed by Pinch and Bijker (1984), shifts the analytical focus from technologies as autonomous, neutral artefacts to technologies as socially constructed entities shaped by actors, values, and power relations. SCOT emphasises that the design, adoption, and use of technologies are contingent on social contexts, interpretive flexibility, and negotiation among stakeholders.

Gender norms critically shape technological development and use. In West African contexts, the predominance of men in engineering, ICT, and industrial design affects which technologies are developed and whose needs are prioritised. For example, agricultural mechanisation programmes often target male farmers, while digital platforms and industrial tools frequently reflect male-centric usability assumptions (Doss, 2018; Wajcman, 2004). SCOT thus provides a theoretical basis for understanding how gendered power relations are inscribed into technology, producing differential access, benefits, and constraints for women and men.

### 3. Political Economy and Postcolonial Perspectives

Political economy and postcolonial theories situate STI within broader structures of global inequality, historical legacies, and capitalist dynamics. Ake (1996) and Mama (2003) highlight how African innovation systems have been shaped by colonial extractive economies, donor-driven research agendas, and global technological hierarchies, often marginalising indigenous knowledge systems and women's contributions.

In Nigeria, postcolonial STI policies have historically emphasised formal, Western-oriented science and engineering, privileged male participation while underfunded local innovation practices in agriculture, health, and environmental management. Political economic approaches underscore that gender inequities in STI are not merely cultural or social issues but are structurally embedded in institutional, economic, and policy systems. They highlight the need to address resource allocation, institutional governance, and power asymmetries to foster inclusive innovation ecosystems that value women's knowledge and participation.

These theoretical perspectives provide a multi-layered understanding of gender in STI and STEM:

a) Feminist epistemology interrogates knowledge production and inclusion of women's perspectives.
b) SCOT elucidates how technologies themselves are shaped by gendered power relations.
c) Political economy and postcolonial theory contextualise STI within historical, economic, and structural inequalities in Africa.

By combining these lenses, scholars and policymakers can better understand why women remain underrepresented in STI, how technologies can reinforce or mitigate inequalities, and what structural reforms are required to create gender-inclusive innovation systems in Nigeria and West Africa.

## Empirical Literature: Thematic Analysis and Discussion

Empirical studies consistently show gender gaps in STEM education and research careers across Africa, driven by socio-cultural norms, limited mentorship, institutional biases, and precarious academic labour conditions (Morley, 2011; UNESCO, 2021). Women's contributions to informal innovation, agriculture, and indigenous knowledge systems remain under-recognised despite their developmental significance. Research on digital technologies reveals a persistent gender digital divide, with women facing lower access to digital skills, infrastructure, and emerging technologies such as artificial intelligence and biotechnology

(Gillwald et al., 2019). These disparities limit women's participation in knowledge economies and innovation-driven development.

### *Gender and the History of Science and Technology*

Empirical studies across disciplines consistently demonstrate that dominant historical narratives of science and technology have systematically marginalised or erased women's contributions. Traditional historiographies tend to celebrate individual male scientists and inventors, while overlooking women's roles as healers, agricultural innovators, technologists, and custodians of indigenous knowledge systems (Schiebinger, 1999; Harding, 1998). This invisibility is not accidental but reflects gendered power relations embedded in the production and documentation of scientific knowledge.

In African contexts, women have historically played central roles in medicinal practices, food preservation technologies, seed selection, textile production, and environmental management. Empirical research on indigenous knowledge systems reveals that women's experiential and embodied knowledge has been crucial to community survival and innovation, particularly in agriculture and health (Hountondji, 2002; Odora Hoppers, 2004). However, such knowledge has often been excluded from formal scientific recognition because it does not conform to Western scientific epistemologies.

Colonial education systems significantly reinforced these exclusions. Empirical historical analyses show that colonial administrations prioritised male education in technical and scientific fields aligned with extractive economies and bureaucratic governance, while restricting women's access to formal schooling and scientific training (Mama, 2003). Women were largely confined to domestic and care-oriented roles, thereby institutionalising gendered divisions of knowledge and labour. These colonial legacies continue to shape contemporary African STI systems, where women remain underrepresented in scientific research, engineering, and technological innovation.

Contemporary empirical data further illustrate the persistence of historical exclusions. UNESCO (2021) reports that women account for less than one-third of researchers globally, with even lower representation in engineering and technology-related fields in many African countries. The historical marginalisation of women in science has therefore translated into enduring structural inequalities, limiting women's visibility, recognition, and leadership within scientific and technological institutions.

### *Gender Biases in Scientific Knowledge*

Empirical scholarship challenges the assumption that science is inherently objective and neutral, demonstrating instead that scientific knowledge is shaped by social values, institutional priorities, and power relations. Feminist science studies provide extensive empirical evidence that research agendas often reflect male-dominated perspectives, resulting in the systematic neglect of issues central to women's lives (Harding, 1991; Schiebinger, 2014). These biases influence what questions are asked, how research is conducted, and whose experiences are considered legitimate sources of data.

In the health sciences, empirical studies have shown that women's bodies and health concerns are frequently underrepresented in clinical research, leading to diagnostic gaps, inappropriate treatments, and adverse health outcomes (Doyal, 2001). Similarly, in agricultural research, technologies and innovations are often designed based on assumptions about male farmers, despite evidence that women constitute a significant proportion of agricultural labour in Africa (FAO, 2011). This gender bias results in technologies that fail to address women's specific needs, constraints, and productive roles.

Methodologically, gender biases manifest through sampling practices, data interpretation, and analytical frameworks that privilege male experiences as universal. Empirical analyses indicate that women's unpaid labour, informal innovation, and care responsibilities are frequently excluded from scientific measurement, thereby reinforcing their invisibility in policy and development planning (Waring, 1988). The absence of gender-disaggregated data further limits the capacity of scientific research to inform inclusive and equitable interventions. Ethical concerns also arise when scientific inquiry neglects gender representation and inclusivity. Empirical evidence suggests that research processes that exclude women from participation—either as researchers or research subjects—compromise both the validity and social relevance of scientific knowledge (Morley, 2011). Gender-blind research not only perpetuates inequality but also undermines innovation by narrowing the range of perspectives and solutions available.

In African STI contexts, these biases are compounded by resource constraints, institutional hierarchies, and limited gender mainstreaming in research governance. Studies of African universities and research institutions reveal persistent gender disparities in funding allocation, authorship, and leadership positions, further entrenching male dominance in knowledge production (Mama, 2003; Morley, 2011). Addressing gender biases in scientific knowledge therefore requires both epistemic and institutional transformation.

***Gender and Technological Design***

Empirical research in science and technology studies demonstrates that technological artefacts are not neutral objects but are shaped by the social identities, values, and assumptions of their designers. The dominance of men in engineering, software development, and industrial design has historically resulted in technologies that embody masculinised norms, priorities, and user imaginaries (Wajcman, 2004). These norms influence design decisions ranging from functionality and aesthetics to usability and safety, often privileging male experiences while marginalising or overlooking women's needs.

Gender-blind technological design frequently produces unintended consequences that increase women's workload or reinforce existing inequalities. Empirical studies in agricultural technology, for example, reveal that mechanised tools and improved seed varieties are often designed for male farmers, despite women's central role in food production across Africa. Such technologies may be physically incompatible with women's bodies, increase time burdens, or require resources and land rights that women do not control (Doss, 2018).

Similarly, household technologies intended to reduce women's domestic labour sometimes shift responsibilities without addressing underlying gendered divisions of labour.

In digital and information technologies, gender biases are evident in software interfaces, algorithms, and data systems. Research on artificial intelligence and machine learning shows that gender-biased training data can reproduce and amplify discrimination in recruitment, credit allocation, and surveillance systems (Noble, 2018). These empirical findings underscore the ethical implications of excluding gender analysis from technological development, particularly as digital technologies increasingly mediate access to social and economic opportunities.

Gender-responsive and user-centred design approaches offer empirically validated pathways towards more inclusive innovation. Such approaches emphasise the active involvement of diverse users throughout the design process, ensuring that technologies respond to differentiated needs, contexts, and capabilities (Schiebinger, 2014). Participatory design initiatives in health, water, and energy sectors in Africa demonstrate that when women are involved as co-designers rather than passive beneficiaries, technological solutions are more sustainable, socially accepted, and developmentally effective. Gender-responsive design therefore enhances not only equity but also the overall quality and impact of technological innovation.

***Women, STEM, and Knowledge Economies***

Empirical evidence consistently highlights women's persistent underrepresentation in STEM education, research, and professional careers, despite policy commitments to gender equality. Structural barriers such as discriminatory recruitment practices, gender stereotypes, unequal access to funding, and limited mentorship significantly constrain women's participation and progression in STEM fields (UNESCO, 2021). These barriers are particularly pronounced in engineering, physics, and information and communication technologies, which are often culturally constructed as masculine domains.

Workplace cultures within STEM institutions further exacerbate gender inequalities. Empirical studies of universities and research organisations reveal that women disproportionately experience precarious employment, heavier teaching and administrative workloads, and limited access to research grants and leadership positions (Morley, 2011). Such conditions undermine women's research productivity and career advancement, reinforcing vertical and horizontal gender segregation within knowledge economies. Brain drain presents an additional challenge to women's participation in STEM, particularly in African contexts. Skilled women scientists and engineers often migrate in search of better research infrastructure, funding opportunities, and gender-inclusive work environments. While migration can enhance individual careers, it simultaneously weakens national innovation systems and reduces the availability of female role models and mentors within domestic STEM institutions (Mama, 2003). Those who remain frequently navigate insecure career pathways characterised by short-term contracts and limited institutional support.

Academic precarity further undermines women's long-term engagement in knowledge economies. Empirical research shows that precarious employment disproportionately affects women due to their greater exposure to care responsibilities and societal expectations around family roles (Standing, 2011). The intersection of gender, precarity, and knowledge production limits women's capacity to contribute fully to research, innovation, and entrepreneurship, thereby constraining the inclusivity and sustainability of knowledge-driven development.

Addressing women's underrepresentation in STEM requires systemic interventions that go beyond increasing enrolment numbers. Empirical evidence supports the effectiveness of targeted funding schemes, mentorship networks, family-friendly workplace policies, and institutional accountability mechanisms in improving women's retention and leadership in STEM (Schiebinger, 2014). Strengthening women's participation in knowledge economies is therefore both a gender equity imperative and a strategic necessity for innovation-led development.

***Gender, Digital Technologies, and Development***

Digitalisation and the emergence of Industry 4.0 technologies—including artificial intelligence (AI), big data, robotics, biotechnology, and digital platforms—are reshaping economies, labour markets, and social relations globally. In development discourse, digital technologies are often framed as neutral tools capable of accelerating growth, improving service delivery, and fostering innovation. However, empirical evidence suggests that digital transformation is deeply gendered and can either exacerbate or reduce existing inequalities depending on the policy and institutional context in which it unfolds.

Without deliberate gender-sensitive digital policies, digitalisation risk widening pre-existing gender gaps in access to education, employment, finance, and political participation. Empirical studies across Africa indicate that women are less likely than men to have access to digital devices, internet connectivity, and advanced digital skills, a phenomenon commonly referred to as the gender digital divide (Gillwald et al., 2019; UNESCO, 2021). These disparities are shaped by intersecting factors such as income inequality, educational attainment, rural–urban divides, and socio-cultural norms that restrict women's mobility and technology use.

Emerging technologies also raise significant ethical and developmental concerns. Research on AI and algorithmic systems shows that gender biases embedded in data sets and design processes can reproduce discrimination in recruitment, credit scoring, health diagnostics, and public surveillance (Noble, 2018). In labour markets, automation and platform-based work may disproportionately displace women concentrated in low-skilled and informal sectors, while new high-skilled digital jobs remain male-dominated. These dynamics underscore the need to integrate gender analysis into digital innovation and governance frameworks.

Conversely, empirical evidence demonstrates that inclusive digital strategies can enhance women's agency, productivity, and socio-economic empowerment. Digital financial services have expanded women's access to credit and savings, while mobile health technologies have improved access to reproductive and maternal health services. In agriculture, digital extension platforms have enabled women farmers to access market information and climate-smart practices. These outcomes are most effective where digital initiatives are accompanied by investments in education, skills development, and supportive institutional frameworks.

**Key Policies and Frameworks on Gender and Digital Technologies**
**Global frameworks**

1. *United Nations 2030 Agenda for Sustainable Development (SDGs 5, 9, and 10)*
2. *UNESCO Recommendation on Science and Scientific Researchers (2017)*
3. *UN Women Gender Equality and Digitalisation Strategy*
4. *OECD Going Digital Framework (gender inclusion components)*

**Regional (Africa)**

1. African Union Digital Transformation Strategy for Africa (2020–2030)
2. AU Science, Technology and Innovation Strategy for Africa (STISA-2024)
3. UNECA Digital Gender Divide Initiative

**National (examples)**

1. National Digital Economy Policies (Nigeria, Kenya, South Africa)
2. National Gender Policies integrating ICT and innovation
3. National Broadband and ICT-for-Development strategies

**Gender Mainstreaming in STI Policy**
Gender mainstreaming in science, technology, and innovation (STI) policy refers to the systematic integration of gender perspectives into the design, implementation, monitoring, and evaluation of STI initiatives. At the normative level, global and regional institutions increasingly recognise gender equality as central to innovation-led development. However, empirical evidence suggests a persistent gap between policy commitments and practical outcomes.

Global frameworks such as the Beijing Platform for Action, CEDAW, and UNESCO's STI-related gender policies emphasise women's equal participation in scientific research, technological development, and innovation governance. At the African regional level, STISA-2024 explicitly identifies gender inclusion as a cross-cutting priority. Despite these commitments, implementation at national and institutional levels remains weak and uneven. Empirical studies reveal that gender mainstreaming in STI is often reduced to symbolic inclusion rather than structural transformation. Women may be included as beneficiaries or participants without meaningful influence over research agendas, funding priorities, or governance structures (Morley, 2011). STI policies frequently lack clear gender objectives, dedicated funding, and institutional accountability mechanisms, limiting their transformative potential.

A critical challenge lies in monitoring and evaluation (M&E). Many STI systems do not collect or utilise gender-disaggregated data on enrolment, employment, research funding, patenting, and innovation outcomes. This data gap constrains evidence-based policymaking and obscures gender patterns of exclusion. Where gender indicators exist, they are often not integrated into performance assessments or budgetary processes. Institutional capacity constraints further undermine gender mainstreaming efforts. Limited expertise in gender analysis among policymakers and research managers results in fragmented or superficial interventions. Empirical evidence suggests that gender-responsive STI policies are most effective when supported by dedicated gender units, clear mandates, and sustained political commitment.

**Key Policies and Frameworks on Gender Mainstreaming in STI**
**Global**

1. Convention on the Elimination of All Forms of Discrimination against Women (CEDAW)
2. Beijing Platform for Action (1995)
3. UNESCO Gender Equality in Science, Technology and Innovation Framework
4. UN Women Gender Mainstreaming Strategy

**Regional (Africa)**

1. AU STI Strategy for Africa (STISA-2024)
2. AU Agenda 2063
3. African Development Bank Gender Strategy

**National**

1. National STI Policies with gender components
2. National Gender Policies aligned with STI
3. Higher education and research funding frameworks incorporating gender criteria

**Table 2**: Summary of Key Gender Issues in Science, Technology, Innovation, and STEM in Nigeria and West Africa

| **Thematic Area** | **Key Gender Issues Identified** | **Empirical Manifestations** | **Development & Policy Implications** |
|---|---|---|---|
| Gender and the History of Science and Technology | Historical invisibility of women; colonial exclusion from formal science | Erasure of women's contributions; male-dominated scientific narratives; marginalisation of indigenous and informal knowledge systems | Persistent underrepresentation of women in STI institutions; weak recognition of women-centred knowledge in policy and innovation systems |
| Gender Biases in Scientific Knowledge | Masculinised research agendas; claims of neutrality masking power relations | Neglect of women's health, unpaid labour, and care work; lack of gender-disaggregated data; exclusionary methodologies | Reduced relevance and ethical quality of research; policy decisions based on incomplete or biased evidence |
| Gender and Technological Design | Gender-blind and male-centred design processes | Technologies incompatible with women's needs; increased workload for women; algorithmic and digital bias | Low adoption rates; reinforcement of gender inequalities; need for participatory and user-centred design frameworks |
| Women, STEM, and Knowledge Economies | Structural barriers to STEM participation; institutional discrimination | Underrepresentation in STEM education and careers; funding gaps; academic precarity; brain drain | Weak national innovation capacity; loss of female talent; limited leadership diversity in knowledge economies |
| Gender, Digital Technologies, and Development | Gender digital divide; exclusion from Industry 4.0 opportunities | Lower access to digital tools, skills, and platforms; biased AI systems; concentration of women in low-skilled digital labour | Risk of widening socio-economic inequalities; missed opportunities for women's empowerment through digital inclusion |
| Gender Mainstreaming in STI Policy | Weak implementation of gender policies; lack of accountability | Tokenistic inclusion; absence of gender indicators; poor monitoring and evaluation mechanisms | Limited policy effectiveness; need for institutionalised gender governance and data-driven decision-making |

The table illustrates that gender inequalities in STI and STEM in Nigeria and West Africa are multi-dimensional and mutually reinforcing, spanning historical exclusion, epistemic bias, technological design, labour markets, digital transformation, and policy implementation. Effective responses therefore require integrated and transformative policy approaches rather than isolated interventions.

**Integrated Discussion: Gendered Dynamics of Science, Technology, Innovation, and STEM in Nigeria and West Africa**

The empirical evidence reviewed across themes demonstrates that gender inequalities in science, technology, innovation (STI), and STEM in Nigeria and West Africa are historically produced, institutionally embedded, and technologically reproduced. These inequalities are not episodic but systemic, cutting across knowledge production, technological design, labour markets, and policy implementation. Understanding these dynamics requires an integrated analytical lens that situates contemporary gender gaps within longer histories of exclusion, colonial legacies, and uneven development trajectories.

Historically, women's contributions to science and technology in West Africa have been rendered largely invisible. Pre-colonial societies relied heavily on women's expertise in agriculture, medicine, environmental management, and artisanal technologies. However, colonial education and research systems systematically privileged Western scientific epistemologies and male participation, marginalising indigenous knowledge systems in which women were central actors. In Nigeria, colonial technical education prioritised male training for administrative and extractive roles, institutionalising gendered hierarchies of knowledge that persist within universities, research institutes, and innovation agencies today. Contemporary patterns of women's underrepresentation in engineering, physical sciences, and technological leadership are therefore rooted in these historical exclusions rather than individual choice or merit alone. These historical legacies are reinforced by enduring gender biases in scientific knowledge production. Empirical studies from Nigerian and West African research institutions reveal that dominant research agendas continue to privilege male-defined priorities, while women's health, unpaid labour, informal innovation, and care responsibilities receive limited scholarly and policy attention. Claims of objectivity and neutrality in science often obscure these biases, masking how institutional power relations shape what counts as legitimate knowledge. The lack of gender-disaggregated data in research design and evaluation further perpetuates women's invisibility, weakening the social relevance and ethical integrity of scientific inquiry.

Gendered power relations are also materially embedded in technological artefacts and innovative processes. In Nigeria and across West Africa, technologies in agriculture, energy, transport, and digital systems are frequently designed without adequate consideration of women's physical, social, and economic realities. Gender-blind design has resulted in innovations that increase women's workload, require resources they do not control, or exclude them from use altogether. In digital systems, algorithmic bias and unequal access to digital infrastructure reproduce existing gender inequalities, particularly for rural and low-income women. Conversely, empirical evidence from participatory and user-centred design initiatives shows that when women are involved as co-designers, technologies are more sustainable, widely adopted, and developmentally impactful.

Women's marginalisation in technological design is closely linked to their underrepresentation in STEM education and knowledge economies. In Nigeria and West Africa, women's participation in STEM remains constrained by structural barriers including gender stereotypes, discriminatory institutional cultures, limited access to research funding, and weak mentorship structures. These challenges are intensified by academic precarity, and brain drain, as highly skilled women scientists and engineers migrate in search of better research conditions and more inclusive work environments. While individual mobility may enhance personal careers, it simultaneously weakens national innovation systems and reduces the presence of female role models within domestic institutions.

Digitalisation and the transition towards Industry 4.0 present both opportunities and risks within this context. Without deliberate gender-sensitive interventions, digital transformation risks deepening existing inequalities by excluding women from emerging high-skilled sectors and reinforcing occupational segregation. In Nigeria and West Africa, gender gaps in digital access, skills, and platform participation remain pronounced, shaped by socio-cultural norms, educational disparities, and infrastructural deficits. However, inclusive digital strategies—such as gender-responsive digital finance, e-agriculture platforms, and mobile health technologies—demonstrate significant potential to enhance women's agency, productivity, and socio-economic empowerment when embedded within supportive policy frameworks.

Despite the proliferation of global, regional, and national policy commitments to gender mainstreaming in STI, implementation gaps remain substantial. Frameworks such as the African Union's STISA-2024, the Digital Transformation Strategy for Africa, and Nigeria's national STI and digital economy policies formally recognise gender inclusion, yet empirical evidence points to weak institutionalisation, limited funding, and inadequate monitoring and evaluation mechanisms. Gender mainstreaming is often treated as an add-on rather than a core governance principle, with insufficient collection and use of gender-disaggregated data to inform decision-making and accountability.

Taken together, the evidence suggests that gender inequality in STI and STEM in Nigeria and West Africa is sustained through mutually reinforcing historical, epistemic, technological, and institutional processes. Addressing these challenges requires a shift from symbolic inclusion towards transformative gender governance in science, technology, and innovation. Such a shift entails rethinking knowledge hierarchies, redesigning technologies with diverse users in mind, reforming STEM institutions, and strengthening policy implementation through robust data systems and accountability structures. An integrated, gender-responsive STI agenda is therefore not only a matter of social justice but a strategic imperative for innovation-led development in Nigeria and West Africa. By expanding participation, valuing diverse knowledge systems, and aligning technological change with social realities, gender-equitable STI systems can enhance innovation quality, resilience, and developmental impact in the region.

## Conclusion

This study demonstrates that gender functions as a fundamental organising principle within science, technology, and innovation (STI) systems in Africa, shaping access to knowledge, participation in innovation, and the distribution of technological benefits. Historical exclusions, colonial legacies, and socially constructed norms have systematically marginalised women and women-centred knowledge systems, resulting in persistent underrepresentation of women in STEM education, research, and innovation governance. Empirical evidence shows that gender biases permeate multiple layers of STI, from the formulation of research agendas and technological design to digitalisation, emerging technologies, and national innovation policies. These biases not only limit women's opportunities but also constrain the relevance, inclusivity, and transformative potential of scientific and technological development.

The study highlights that technologies are socially constructed, often embedding masculinised norms that disadvantage women in both rural and urban contexts. Gender-blind digitalisation and Industry 4.0 innovations risk reinforcing structural inequalities if interventions fail to integrate women's perspectives. Similarly, the absence of gender-disaggregated data in policy and research undermines the effectiveness of innovation governance and perpetuates epistemic inequities.

Addressing these challenges requires moving beyond tokenistic inclusion towards both structural and epistemic transformation. Structural transformation entails reforms in institutional governance, research funding, STEM education, and technological innovation processes to ensure equitable participation, leadership opportunities, and resource allocation for women. Epistemic transformation involves recognising women lived experiences, indigenous knowledge systems, and gendered perspectives as legitimate and valuable sources of scientific knowledge. Integrating feminist epistemology, SCOT, and postcolonial political economy perspectives can guide such transformations by revealing how knowledge, technology, and innovation are socially situated and historically contingent.

Policy implications are clear: national and regional STI frameworks must embed gender mainstreaming as a core governance principle, supported by dedicated gender units, measurable indicators, and robust monitoring and evaluation systems. Digital strategies and technological innovation policies should adopt user-centred, participatory, and gender-responsive design approaches to ensure inclusivity and equity in both access and outcomes. Additionally, investments in women's STEM education, mentorship, and research funding are critical for building sustainable, locally grounded, and innovation-driven knowledge economies. In conclusion, advancing gender equity in STI is not merely a matter of fairness; it is a strategic imperative for inclusive development and sustainable innovation. By dismantling structural barriers, challenging epistemic hierarchies, and fostering women's participation at every level of science and technology, African countries—particularly Nigeria and West Africa—can unlock the full potential of STI to drive economic growth, social progress, and development that benefits all members of society.

**Policy Recommendations**

**1. Institutional Reform**

STI institutions in Nigeria and West Africa—including universities, research institutes, innovation hubs, and technology parks—require comprehensive gender-responsive governance reforms. Affirmative action policies should be implemented to ensure women's representation in leadership, decision-making committees, and research management structures. Institutional accountability mechanisms must link gender equity indicators, such as recruitment, promotion, and funding allocation, to measurable performance outcomes. In practice, this could involve integrating gender targets into annual institutional reports and establishing independent oversight units to monitor compliance. By embedding gender considerations into the core governance of STI institutions, these reforms move beyond tokenistic inclusion and ensure that women have meaningful influence over research agendas, innovation priorities, and organisational culture.

**2. Capacity Building**

Enhancing women's participation in STEM and innovation sectors requires deliberate investments in capacity building, mentorship, and funding support. Mentorship programmes can connect early-career female scientists, engineers, and innovators with senior role models in academia, industry, and policy, providing guidance and fostering professional networks. Training initiatives should focus on emerging technologies, research methodologies, entrepreneurship, and digital literacy, equipping women to compete effectively in rapidly evolving knowledge economies. Dedicated funding mechanisms—such as grants for women-led research projects and innovation start-ups—can help to mitigate structural barriers, including discriminatory access to resources and limited institutional support. Empirical evidence shows that such capacity-building interventions improve retention, productivity, and leadership outcomes for women in STEM, thereby strengthening national and regional innovation ecosystems.

**3. Inclusive Innovation**

Technological development and innovation processes must adopt gender-responsive and user-centred design frameworks. This involves actively engaging women at all stages of technological development—from ideation and prototyping to deployment and evaluation. Gender audits of existing technologies, including digital platforms, agricultural tools, and industrial equipment, can identify embedded biases and usability gaps. Incentivising research institutions, start-ups, and private firms to develop technologies that address women's specific needs enhances adoption, relevance, and impact. By prioritising inclusive innovation, policymakers and designers can ensure that new technologies do not exacerbate existing gender inequalities but instead support women's economic participation, social empowerment, and overall well-being.

**4. Data and Monitoring**

Robust evidence systems are critical for gender-sensitive policymaking in STI. National and institutional databases should systematically collect gender-disaggregated data on participation in STEM education, research outputs, innovation projects, leadership roles, patents, and digital access. Integrating these data into monitoring and evaluation (M&E) frameworks enables policymakers to assess progress, identify gaps, and recalibrate interventions effectively. Regular gender audits of STI policies and programmes can strengthen accountability, ensure transparency, and prevent superficial or symbolic gender inclusion. By institutionalising data-driven evaluation mechanisms, countries can make informed decisions that advance equity while improving the quality and impact of innovation systems.

**5. Indigenous Knowledge Integration**

Women's informal and indigenous knowledge represents a critical resource for innovation and development, yet it remains undervalued in formal STI systems. Policy measures should create mechanisms to document, validate, and integrate indigenous technologies and community-based innovations into national innovation frameworks. Knowledge exchange platforms can facilitate interaction between local innovators, researchers, and policymakers, enhancing both the visibility and application of women-centred innovations. Support for intellectual property protection, commercialization, and entrepreneurship ensures that women innovators gain recognition, agency, and sustainable livelihoods. Integrating indigenous knowledge not only enhances epistemic diversity but also strengthens the relevance and sustainability of innovation across rural and marginalised communities.

## 6. Digital Inclusion

The transition to digitalisation and Industry 4.0 technologies presents both opportunities and risks for gender equality. To prevent the reinforcement of existing disparities, governments and institutions should implement targeted digital inclusion policies. This includes expanding access to affordable devices, reliable internet connectivity, and ICT infrastructure, particularly for women and girls in rural or underserved areas. Tailored digital literacy and skills training programmes can enhance women's participation in AI, robotics, data analytics, and other high-tech sectors. Additionally, policies must ensure ethical governance of emerging technologies, addressing algorithmic bias, data privacy, and discriminatory practices. By bridging the gender digital divide, digital inclusion initiatives empower women to participate fully in knowledge economies and leverage technological innovation for social and economic development.

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