



Capacity Building for Inclusive and Sustainable Development in Science, Engineering, and Technology: A Strategic Review

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Abstract

Capacity building has emerged as a fundamental strategy for achieving inclusive and sustainable development, particularly in science, engineering, and technology (SET), where innovation drives socioeconomic transformation and environmental sustainability. Despite significant advances in scientific knowledge and technological innovation, many developing countries continue to face persistent challenges, including inadequate technical expertise, weak institutional capacity, limited research infrastructure, and unequal access to quality education and technological resources. This paper examines the critical role of capacity building in strengthening human capital, institutional effectiveness, innovation ecosystems, and equitable access to SET for sustainable development. The study adopts a narrative review methodology, guided by an explicit review protocol, to synthesise evidence on capacity-building strategies and their contribution to inclusive and sustainable development. A structured search of Scopus, Web of Science, ScienceDirect, SpringerLink, IEEE Xplore, and Google Scholar, conducted in March 2025 using defined search strings and inclusion/exclusion criteria, initially identified 214 records; after screening, 96 sources (72 peer-reviewed journal articles and 24 institutional or policy reports) published between 2008 and 2024 were retained for thematic analysis. The analysis is anchored in an integrated conceptual framework combining Human Capital Theory, Innovation Systems Theory, and the Capability Approach. The review identifies educational reform, technical and vocational skills development, innovation promotion, digital inclusion, interdisciplinary collaboration, supportive policy frameworks, and strategic partnerships as key drivers of sustainable capacity development, while highlighting major barriers such as inadequate funding, brain drain, gender disparities, infrastructural deficits, and weak policy implementation. Five illustrative case studies are examined using a consistent context-intervention-outcome-limitation-lesson structure, and the discussion moves beyond description to critically assess implementation contradictions, sustainability risks, and financing constraints. The paper concludes with stakeholder-specific, time-bound recommendations, each linked to required resources and measurable indicators, for governments, higher education institutions, industry, development partners, and researchers seeking to strengthen national and regional innovation systems in support of the Sustainable Development Goals.

Keywords: Capacity Building; Sustainable Development; Inclusive Development; Science and Technology; Engineering Education; Innovation Ecosystems; Human Capital Development; STEM Education; Digital Inclusion; Policy Development

1.0 Introduction

The pursuit of sustainable development has become a defining global priority in response to increasingly complex socioeconomic, environmental, and technological challenges confronting nations in the twenty-first century. Rapid population growth, climate change, environmental degradation, food insecurity, public health emergencies, widening socioeconomic inequalities, and accelerating technological transformation have intensified the demand

for innovative, inclusive, and sustainable solutions. Recognizing these interconnected challenges, the 2030 Agenda for Sustainable Development, adopted by the United Nations in 2015, established seventeen Sustainable Development Goals (SDGs) aimed at promoting economic prosperity, social inclusion, and environmental sustainability through coordinated global action. Achieving these goals requires substantial investments in human capital, scientific knowledge, technological innovation, and institutional capacity, which constitute the foundation of sustainable national development (United Nations, 2015; United Nations, 2023).

Science, Engineering, and Technology (SET) have consistently served as powerful drivers of economic growth, industrial transformation, environmental management, and social progress. Scientific research generates new knowledge for addressing emerging development challenges, engineering transforms scientific discoveries into practical applications through innovative design and infrastructure development, while technology facilitates the efficient delivery of goods, services, information, and public utilities across society. Collectively, these disciplines underpin improvements in agricultural productivity, healthcare delivery, renewable energy development, digital transformation, climate resilience, manufacturing competitiveness, water resource management, transportation systems, and disaster risk reduction. Consequently, countries that have invested strategically in scientific research, engineering education, technological innovation, and institutional development have generally achieved stronger innovation capacity, improved productivity, and enhanced economic competitiveness (UNESCO, 2015; UNCTAD, 2021; World Economic Forum, 2019).

Despite these significant contributions, the benefits of science, engineering, and technology remain unevenly distributed across countries and population groups. Many developing nations continue to experience limited research capacity, inadequate funding for scientific innovation, obsolete laboratory facilities, insufficient digital infrastructure, weak university-industry collaboration, shortages of highly skilled professionals, and persistent brain drain. These structural constraints significantly reduce their ability to generate indigenous technologies capable of addressing local development challenges. Furthermore, inequalities in access to quality education, digital technologies, technical training, and research opportunities disproportionately affect women, rural populations, persons with disabilities, and other marginalized groups, thereby limiting inclusive participation in scientific and technological advancement (UNESCO, 2015; World Bank, 2017; UN Women, 2020; Broadband Commission for Sustainable Development, 2023).

Capacity building has therefore emerged as a strategic mechanism for addressing these disparities and strengthening the contribution of SET to sustainable development. Capacity building involves the process through which individuals, organizations, and societies develop, strengthen, and sustain the capabilities required to achieve development objectives over time (UNDP, 2008). Within the context of science, engineering, and technology, capacity building extends beyond technical competence to include institutional strengthening, research and innovation systems, leadership development, digital literacy, entrepreneurial skills, policy formulation, governance, and knowledge management. Effective capacity-building initiatives enable countries to generate scientific knowledge, adapt emerging technologies, stimulate innovation, enhance productivity, and develop context-specific solutions to socioeconomic and environmental challenges (UNDP, 2008; UNCTAD, 2021).

Recent global developments further underscore the importance of strengthening capacity within SET sectors. The Fourth Industrial Revolution, characterized by rapid advances in artificial intelligence, robotics, big data analytics, biotechnology, the Internet of Things, additive manufacturing, and renewable energy technologies, is fundamentally transforming economies and labour markets. These technological shifts present unprecedented opportunities for sustainable development but simultaneously widen existing disparities between countries with strong scientific and technological capabilities and those with limited innovation capacity. Consequently, enhancing human capital, institutional effectiveness, digital readiness, and technological capability has become increasingly essential for enabling developing countries to participate meaningfully in the global knowledge economy (World Economic Forum, 2019; OECD, 2023; UNCTAD, 2021).

In Africa, and particularly in Sub-Saharan Africa, the need for robust capacity-building strategies is especially urgent. Although the continent possesses abundant natural resources, a youthful population, and considerable innovation potential, scientific productivity, research funding, technological commercialization, and industrial competitiveness remain comparatively low. Higher education institutions frequently encounter inadequate infrastructure, insufficient research financing, limited international collaboration, outdated curricula, and weak linkages with industry. These challenges constrain the development of a highly skilled workforce capable of driving industrialization, technological innovation, and sustainable economic transformation. Strengthening institutional capacity, improving STEM education, expanding research investment, and promoting inclusive innovation ecosystems therefore represent critical priorities for achieving sustainable development objectives (UNESCO, 2015; UNIDO, 2018; World Bank, 2017).

Capacity building also plays a central role in promoting inclusivity within science, engineering, and technology systems. Inclusive development requires that scientific knowledge, technological innovations, educational opportunities, and economic benefits be accessible to all segments of society irrespective of gender, socioeconomic status, geographical location, disability, or cultural background. Promoting equitable participation not only enhances social justice but also broadens the diversity of ideas, perspectives, and innovations available to address increasingly complex global challenges. Addressing gender inequalities and expanding opportunities for underrepresented groups remain important priorities for achieving inclusive participation in SET fields (UNESCO, 2017; UN Women, 2020).

1.1 Positioning This Review Against Prior Literature

A number of prior reviews have examined components of the capacity-building agenda, but each has done so with a narrower lens than is adopted here. Muchie and Baskaran (2010) focused specifically on the role of universities as sites of research capacity building, without extending the analysis to digital inclusion, gender equity, or policy financing. Peercy and Svenson (2018) examined higher-education investment patterns in developing countries but treated innovation ecosystems and workforce skills development as peripheral concerns. Phale et al. (2021) modelled the statistical relationship between knowledge-economy indicators and capacity building across the Southern African Development Community, offering strong quantitative evidence but limited attention to institutional mechanisms, case-level detail, or policy sequencing. Sector-specific reviews, such as those on innovation-ecosystem governance in Sub-Saharan African universities, similarly concentrate on technology-transfer structures rather than on the wider human-capital, gender, and digital-inclusion dimensions of capacity building (Governance Models for University-Led Innovation Ecosystems in Sub-Saharan Africa, 2024).

What existing reviews have not done is integrate these strands, human capital development, institutional strengthening, innovation ecosystems, digital inclusion, gender equity, and policy financing, within a single analytical framework and connect them through a common set of theoretical lenses. Existing studies also rarely subject illustrative case examples to a structured comparative format that separates context, intervention mechanism, outcome, and limitation, which limits the transferability of their lessons. This review addresses these gaps by (i) grounding the discussion in an explicit theoretical framework, (ii) applying a reproducible narrative-review protocol, (iii) analysing case studies through a uniform comparative structure, and (iv) translating findings into recommendations that specify responsible stakeholders, timeframes, resource requirements, and measurable indicators.

This paper addresses this gap by critically reviewing the major strategies for strengthening capacity building in science, engineering, and technology as a pathway to inclusive and sustainable development. Specifically, the paper examines the role of educational reform, technical and vocational skills development, innovation ecosystems, digital transformation, institutional strengthening, policy frameworks, strategic partnerships, and equitable access to scientific knowledge in enhancing sustainable development outcomes. The paper further identifies major implementation challenges, presents illustrative international case studies, and proposes practical policy recommendations for governments, higher education institutions, development agencies, industry stakeholders, and development partners.

The significance of this review lies in its integrated perspective on capacity building as a multidimensional process encompassing human, institutional, technological, and policy capacities. By synthesizing contemporary evidence and situating it within an explicit theoretical and methodological framework, the paper contributes to ongoing discussions on strengthening national innovation systems and provides actionable insights for policymakers, researchers, educators, and development practitioners seeking to accelerate progress towards the Sustainable Development Goals through science, engineering, and technology.

2. Theoretical Framework

To move beyond a purely descriptive account, this review is grounded in three complementary theoretical perspectives that together explain why capacity building matters for inclusive and sustainable development, how it operates at different levels of society, and what constitutes genuine developmental progress.

2.1 Human Capital Theory

Human Capital Theory (Becker, 1964; Schultz, 1961) conceptualises education, training, and skills acquisition as investments that raise individual productivity and, in aggregate, national economic output. Applied to SET, the theory explains why educational reform and workforce skills development (discussed in Section 5) are treated as foundational rather than peripheral: without a critical mass of technically competent individuals, neither innovation systems nor policy frameworks can function. The theory has, however, been criticised for treating

skills accumulation as sufficient for development on its own, without accounting for whether institutions and markets exist to absorb and reward those skills. This review therefore uses Human Capital Theory to explain the individual-level dimension of capacity building while relying on the two frameworks below to address its institutional and normative dimensions.

2.2 Innovation Systems Theory

Innovation Systems Theory (Freeman, 1987; Lundvall, 1992) shifts the unit of analysis from the individual to the network of relationships among universities, firms, government agencies, and intermediary organisations that jointly generate, diffuse, and apply knowledge. This perspective underpins the review's treatment of research and innovation ecosystems, university-industry collaboration, and intellectual property systems (Section 5.3), and provides the analytical basis for interpreting why isolated interventions, such as funding a single laboratory without corresponding industry linkages or regulatory support, often fail to produce sustained innovation outcomes. It also supports the Triple Helix and governance-model literature on university-led innovation ecosystems in Sub-Saharan Africa used elsewhere in this review.

2.3 The Capability Approach

The Capability Approach (Sen, 1999; Nussbaum, 2011) reframes development as the expansion of the real freedoms and opportunities available to individuals, rather than simply the accumulation of income, skills, or infrastructure. This normative lens is essential for the inclusion dimension of the review: it explains why equitable access to SET knowledge and infrastructure (Section 5.4) and gender equality and social inclusion (Section 6.3) are treated as constitutive of development success rather than as secondary distributive concerns. Under this framework, a capacity-building initiative that increases aggregate technological output while leaving structural barriers facing women, rural populations, or persons with disabilities unaddressed would be considered only partially successful.

2.4 Integrated Conceptual Framework

This review integrates the three perspectives into a single conceptual framework operating at three levels: (i) the individual level, where Human Capital Theory explains skills and knowledge accumulation; (ii) the institutional and systemic level, where Innovation Systems Theory explains how those skills are organised into productive innovation activity through institutions, policy, and partnerships; and (iii) the normative level, where the Capability Approach evaluates whether the resulting development is genuinely inclusive. Each subsequent section of this review is explicitly mapped to one or more of these levels, and the case studies in Section 7 and the critical analysis in Section 8 return to this framework to assess whether capacity-building initiatives achieved individual, institutional, and inclusive outcomes simultaneously, or only some of them.

3. Methodology

This study adopted a narrative literature review approach, structured around an explicit and reproducible review protocol, to examine capacity-building strategies for promoting inclusive and sustainable development in science, engineering, and technology (SET). A narrative rather than a systematic design was selected because the review's objective is conceptual integration across disciplinary and institutional literatures rather than exhaustive quantitative synthesis of a narrowly bounded research question; nonetheless, the search and screening procedures below follow systematic-review conventions to improve transparency and reproducibility.

3.1 Search Strategy

The literature search was conducted between 3 and 21 March 2025 in the following databases: Scopus, Web of Science, ScienceDirect, SpringerLink, IEEE Xplore, Google Scholar, and Wiley Online Library. In addition, the institutional repositories of the United Nations (UN), United Nations Development Programme (UNDP), United Nations Educational, Scientific and Cultural Organization (UNESCO), World Bank, Organisation for Economic Co-operation and Development (OECD), International Labour Organization (ILO), International Telecommunication Union (ITU), and the Intergovernmental Panel on Climate Change (IPCC) were searched directly for policy reports.

Boolean search strings combined a capacity-building term with a domain term, for example: ("capacity building" OR "capacity development") AND ("science and technology" OR "engineering education" OR "innovation ecosystem" OR "innovation system") AND ("sustainable development" OR "inclusive development"); and ("STEM education" OR "technical and vocational education") AND ("developing countries" OR "Africa" OR "Sub-Saharan Africa") AND ("digital inclusion" OR "gender" OR "policy"). Titles and abstracts were limited to English-language publications.

3.2 Inclusion and Exclusion Criteria

Sources were included if they: (a) addressed capacity building, innovation systems, STEM/TVET education, digital inclusion, or institutional strengthening within a SET context; (b) were peer-reviewed journal articles, books, or authoritative institutional/policy reports; (c) were published between 2008 and 2024, with earlier

seminal theoretical works admitted where necessary to establish conceptual foundations; and (d) provided sufficient methodological or empirical detail to support synthesis. Sources were excluded if they: (a) addressed capacity building outside a SET context (for example, purely clinical or humanitarian capacity building unrelated to science, engineering, or technology); (b) were opinion pieces, editorials, or non-peer-reviewed blog content; (c) were duplicate records; or (d) could not be retrieved in full text.

3.3 Screening and Selection

The initial search identified 214 records across all databases and repositories. After removal of 31 duplicate records, 183 records remained for title and abstract screening. Screening against the inclusion and exclusion criteria above removed a further 62 records judged not to meet topical relevance requirements, leaving 121 records for full-text assessment. Full-text review excluded 25 additional records for insufficient methodological detail or thematic misalignment, resulting in a final set of 96 sources: 72 peer-reviewed journal articles and 24 institutional or policy reports, published between 2008 and 2024, retained for thematic analysis and citation in this review.

3.4 Thematic Analysis

The selected literature was analysed using thematic analysis, following the six-phase process described by Braun and Clarke (2006): familiarisation with sources, generation of initial codes, searching for themes, reviewing themes against the coded data, defining and naming themes, and producing the synthesis presented in this paper. Recurring concepts were organised into major themes, including educational reform, skills development, innovation ecosystems, research and institutional capacity, digital inclusion, policy frameworks, and strategic partnerships. Each theme was subsequently mapped onto the theoretical framework presented in Section 2 to ensure that the synthesis was analytically, and not merely descriptively, organised. This process provided the basis for discussing effective capacity-building strategies, implementation challenges, and policy recommendations for advancing inclusive and sustainable development.

3.5 Limitations of the Review Methodology

As a narrative rather than systematic review, this study does not apply formal risk-of-bias or quality-appraisal instruments to individual sources, and the thematic coding, while structured, involved interpretive judgement rather than independent dual coding. The restriction to English-language sources may also have excluded relevant scholarship published in other languages, particularly francophone and lusophone African literature on capacity building. These limitations are consistent with the conceptual-integration objective of the review but should be considered when generalising its conclusions.

4. The Role of Science, Engineering, and Technology in Inclusive Sustainable Development

Science, engineering, and technology (SET) constitute fundamental drivers of sustainable development by providing knowledge, tools, and innovative solutions required to address complex global challenges. The achievement of inclusive sustainable development depends not only on economic growth but also on the ability of societies to improve social well-being, protect environmental resources, and ensure equitable access to opportunities. In this context, SET serves as a transformative force that connects scientific discoveries with practical solutions capable of improving livelihoods, strengthening economies, and enhancing environmental resilience (United Nations, 2015; UNESCO, 2015). Consistent with the Human Capital and Innovation Systems perspectives introduced in Section 2, the following subsections examine SET's economic, social, and environmental contributions in turn.

4.1 Science, Engineering, and Technology as Drivers of Economic Development

SET contributes significantly to economic development by stimulating innovation, improving productivity, creating employment opportunities, and supporting industrial transformation. Scientific research generates new knowledge, while engineering converts this knowledge into practical systems, products, and infrastructure. Similarly, technology facilitates efficient production processes, digital transformation, and improved access to markets and services (UNCTAD, 2021; UNIDO, 2018).

Countries with strong scientific and technological capabilities have demonstrated greater competitiveness through innovation-driven industries, advanced manufacturing systems, and knowledge-based economies. In developing countries, strengthening SET capacity provides opportunities for local innovation, technology adaptation, entrepreneurship development, and improved utilization of indigenous resources. For example, advancements in agricultural technologies, renewable energy systems, and digital platforms have enhanced productivity and supported economic inclusion among rural and underserved communities (UNESCO, 2015; World Economic Forum, 2019). However, the contribution of SET to economic development depends largely on the availability of skilled human resources, effective research institutions, supportive policies, and functional innovation ecosystems. Without adequate investment in education, research infrastructure, and technology transfer mechanisms, technological advancement may remain externally dependent and fail to address local development priorities (UNCTAD, 2021; World Bank, 2017). Phale et al. (2021) provide econometric evidence from the

Southern African Development Community showing that knowledge-economy capacity, comprising education, innovation, information infrastructure, and institutional regime quality jointly, rather than any single factor in isolation, predicts sustained economic growth, reinforcing the systemic view of capacity building adopted in this review.

4.2 SET Contribution to Social Inclusion and Human Development

Beyond economic benefits, SET plays an important role in promoting social equity by improving access to essential services such as healthcare, education, communication, and financial systems. Digital technologies, for instance, have expanded access to online education, e-health services, digital financial platforms, and government services, particularly among populations previously excluded from conventional systems (ITU, 2022; Broadband Commission for Sustainable Development, 2023). In education, SET facilitates innovative teaching and learning approaches through digital learning platforms, virtual laboratories, and open educational resources. These technologies have the potential to reduce geographical and socioeconomic barriers by providing wider access to knowledge and skills development opportunities. Similarly, engineering innovations in areas such as affordable housing, water supply systems, sanitation technologies, and renewable energy solutions contribute directly to improved living conditions (European Commission, 2020; UNESCO, 2017). Nevertheless, technological advancement does not automatically guarantee inclusivity. Persistent challenges such as the digital divide, unequal access to infrastructure, limited digital literacy, and gender disparities in STEM participation continue to restrict the ability of vulnerable groups to benefit from technological progress. Consistent with the Capability Approach outlined in Section 2.3, capacity-building strategies must therefore prioritize equitable access, ensuring that technological development expands real opportunities for participation rather than widening existing inequalities (ITU, 2022; Broadband Commission for Sustainable Development, 2023; UN Women, 2020).

4.3 SET and Environmental Sustainability

Environmental sustainability represents another critical area where SET provides essential solutions. Climate change, resource depletion, biodiversity loss, and environmental pollution require innovative approaches based on scientific evidence and technological advancement. SET enables the development of renewable energy systems, sustainable agricultural practices, efficient waste management technologies, climate monitoring systems, and environmentally friendly production methods (IPCC, 2023; UNIDO, 2018). Engineering solutions are particularly important in designing resilient infrastructure capable of adapting to changing environmental conditions. Renewable energy technologies, precision agriculture, circular economy approaches, and clean production systems demonstrate how technological innovation can reduce environmental impacts while supporting economic development (IPCC, 2023; UNCTAD, 2021). However, achieving environmentally sustainable development requires not only technological innovation but also effective knowledge transfer, skilled professionals, appropriate policies, and institutional capacity. Developing countries often face challenges related to technology access, financing, maintenance capacity, and adaptation of imported technologies to local conditions. Strengthening local scientific and engineering capabilities is therefore essential for developing sustainable solutions that are appropriate, affordable, and context-specific (UNESCO, 2015; UNCTAD, 2021).

4.4 The Need for Inclusive SET Capacity Development

Although SET offers significant opportunities for sustainable development, its benefits remain unevenly distributed globally. Limited access to quality STEM education, inadequate research funding, weak innovation systems, and insufficient technological infrastructure continue to constrain progress, particularly in developing regions. These challenges highlight the need for comprehensive capacity-building approaches that strengthen individual skills, institutional capabilities, and enabling policy environments (UNESCO, 2015; World Bank, 2017). Inclusive SET development requires deliberate strategies that promote participation among women, youth, rural populations, and marginalized communities. Expanding access to STEM education, strengthening vocational training, supporting research institutions, improving digital connectivity, and encouraging collaboration between academia, industry, and government are essential for building societies capable of generating and applying scientific and technological solutions (UNESCO, 2017; OECD, 2018; UN Women, 2020).

Therefore, science, engineering, and technology should not be viewed merely as technical fields but as strategic instruments for achieving sustainable development. Their contribution depends on the capacity of individuals, institutions, and societies to create, adapt, and effectively utilize knowledge and innovation. Building such capacity is fundamental to ensuring that technological advancement becomes inclusive, sustainable, and responsive to global development challenges (United Nations, 2015; UNCTAD, 2021).

5. Dimensions of Capacity Building in Science, Engineering, and Technology

Capacity building in science, engineering, and technology (SET) is a multidimensional process that extends beyond the acquisition of technical knowledge and skills. It involves strengthening individual competencies, institutional capabilities, innovation systems, and policy environments required to generate, adopt, and effectively

utilize scientific and technological solutions. For SET to contribute meaningfully to inclusive and sustainable development, capacity-building initiatives must address educational systems, workforce development, research and innovation infrastructure, equitable access to knowledge, and institutional collaboration (UNDP, 2008; UNCTAD, 2021).

5.1 Educational Reform and Access to SET Education

A strong educational foundation is essential for developing the human capital required to advance science, engineering, and technology. Early exposure to science, technology, engineering, and mathematics (STEM) education promotes critical thinking, creativity, analytical reasoning, and problem-solving abilities necessary for innovation and sustainable development (UNESCO, 2017; OECD, 2018). However, many education systems, particularly in developing countries, continue to face challenges including outdated curricula, inadequate learning facilities, limited practical training opportunities, and insufficient numbers of qualified STEM educators. These challenges reduce the ability of graduates to acquire the competencies required in modern knowledge-based economies (World Bank, 2017; UNESCO, 2015). Therefore, educational reforms should focus on developing curricula that are relevant to local development challenges while incorporating emerging technologies, interdisciplinary learning, entrepreneurship, and practical problem-solving approaches. Strengthening teacher capacity through continuous professional development is equally important to ensure effective delivery of SET education (European Commission, 2020; OECD, 2018). Furthermore, inclusive access to SET education must be prioritized by addressing barriers affecting women, rural populations, low-income communities, and persons with disabilities. Strategies such as scholarships, flexible learning pathways, digital learning platforms, and targeted mentorship programmes can increase participation and promote diversity within SET fields (UNESCO, 2017; UN Women, 2020).

5.2 Skills Development and Workforce Capacity Enhancement

Beyond formal education, continuous skills development is necessary to maintain a workforce capable of responding to rapidly changing technological environments. The increasing influence of automation, artificial intelligence, digitalization, and advanced manufacturing requires individuals to continually update their knowledge and competencies (World Economic Forum, 2019; OECD, 2023). Technical and Vocational Education and Training (TVET) programmes play a significant role in preparing skilled personnel for industry and community-based technological applications. Effective TVET systems should be aligned with labour market demands, industrial needs, and emerging technological trends. This requires strong collaboration between educational institutions, industries, professional organizations, and government agencies (ILO, 2019; OECD, 2018). Lifelong learning is also critical because technological advancement continuously changes occupational requirements. Professional training, certification programmes, entrepreneurship development, and digital literacy initiatives provide opportunities for individuals to remain productive and adaptable throughout their careers (ILO, 2019; World Bank, 2023). Developing entrepreneurial capacity among SET graduates is particularly important for transforming knowledge into practical innovations. By combining technical expertise with business skills, graduates can create enterprises, generate employment, and contribute to local economic development (UNCTAD, 2021; World Economic Forum, 2019).

5.3 Strengthening Research and Innovation Ecosystems

A functional innovation ecosystem is essential for converting scientific knowledge into practical solutions for sustainable development. Such ecosystems require strong research institutions, modern infrastructure, effective knowledge transfer mechanisms, and collaboration among universities, industries, governments, and communities (UNESCO, 2015; UNCTAD, 2021). Investment in research and development (R&D) infrastructure, including laboratories, technology centres, digital resources, and research networks, enhances the ability of institutions to generate innovative solutions. However, infrastructure development must be complemented by adequate funding, skilled researchers, effective research management systems, and supportive institutional policies (World Economic Forum, 2019; WIPO, 2021). University-industry collaboration is particularly important because it facilitates technology transfer, commercialization of research outputs, and development of solutions aligned with societal and industrial needs. Innovation hubs, incubators, and accelerators can further support entrepreneurs and start-up enterprises by providing technical guidance, mentorship, networking opportunities, and access to financing (National Academies of Sciences, Engineering, and Medicine, 2017; UNCTAD, 2021). Analyses of university-led innovation ecosystems in Sub-Saharan Africa identify Triple Helix, entrepreneurial-university, technology-transfer-office, and hybrid governance models as the dominant institutional arrangements through which such collaboration is organised, with hybrid structures generally proving most resilient in resource-constrained settings. Strong intellectual property systems are also necessary to encourage innovation while ensuring that technological benefits are distributed equitably. Developing countries must therefore strengthen

mechanisms that protect innovation, promote knowledge sharing, and encourage local technology development (WIPO, 2021).

5.4 Promoting Equitable Access to SET Knowledge and Infrastructure

Capacity building cannot be achieved solely through individual skills development; it also requires ensuring that communities have access to scientific knowledge, technological resources, and digital infrastructure. Unequal access to technology remains a major barrier to inclusive development, particularly among rural and disadvantaged populations (Broadband Commission for Sustainable Development, 2023; ITU, 2022).

Open science initiatives, open-access publications, digital learning resources, and knowledge-sharing platforms can democratize access to scientific information. Similarly, affordable and context-appropriate technologies are essential for ensuring that innovation benefits reach underserved communities (UNESCO, 2021; UNESCO, 2017). Expansion of digital infrastructure, including reliable internet connectivity, affordable devices, and digital literacy programmes, is fundamental for reducing the digital divide. Community technology centres and local innovation spaces can provide opportunities for individuals and communities to acquire technological skills and participate in knowledge-based activities (ITU, 2022; Broadband Commission for Sustainable Development, 2023). Ultimately, equitable access ensures that SET becomes a tool for empowerment rather than a source of increased inequality. Achieving this requires coordinated efforts involving governments, educational institutions, industries, and development organizations to create inclusive innovation systems that enable all groups to participate in scientific and technological advancement (United Nations, 2015; UNCTAD, 2021).

6. Key Principles for Effective Capacity Building in Science, Engineering, and Technology

For capacity-building initiatives to achieve long-term impact, they must be guided by principles that promote sustainability, inclusiveness, and local relevance. Effective capacity building requires more than transferring knowledge or providing infrastructure; it requires developing systems that enable individuals and institutions to continuously generate, adapt, and apply knowledge. Sustainable capacity development therefore depends on strengthening human capabilities, institutional structures, innovation systems, and enabling policy environments (UNDP, 2008; UNCTAD, 2021).

6.1 Local Ownership and Stakeholder Participation

Successful capacity-building programmes should be driven by local priorities and involve active participation from beneficiaries, institutions, governments, and communities. Approaches developed without adequate consideration of local contexts often fail because they may not address actual needs or may lack community acceptance (UNDP, 2008). Local ownership improves sustainability by ensuring that communities and institutions develop responsibility for maintaining and expanding capacity-building outcomes. Therefore, external support should focus on strengthening existing systems rather than replacing local capabilities. This approach promotes institutional resilience, knowledge transfer, and long-term development impact (UNDP, 2008; UNESCO, 2017).

6.2 Interdisciplinary and Transdisciplinary Approaches

Modern development challenges such as climate change, food insecurity, energy transitions, and public health crises are complex and cannot be solved through single disciplines alone. Effective capacity building requires collaboration among science, engineering, technology, social sciences, humanities, policymakers, industries, and indigenous knowledge systems (UNESCO, 2017; IPCC, 2023). Interdisciplinary approaches encourage the integration of diverse expertise, while transdisciplinary approaches promote collaboration between researchers, practitioners, industries, and communities. Such approaches increase the relevance, acceptance, and sustainability of technological solutions by ensuring that innovations respond to real societal needs and environmental conditions (Pohl & Hirsch Hadorn, 2007; UNCTAD, 2021).

6.3 Gender Equality and Social Inclusion

Inclusive capacity building must actively address gender disparities and social inequalities within SET fields. Women and marginalized groups remain underrepresented in many science and engineering disciplines due to educational barriers, cultural constraints, limited mentorship opportunities, and unequal access to resources (UN Women, 2020; UNESCO, 2017). Jackson et al. (2022) show, in a review of science granting councils across Sub-Saharan Africa, that women researchers continue to face disproportionate domestic and social obligations and report needing greater institutional support to advance into research leadership, underscoring that gender gaps in SET persist even where formal access barriers have been reduced. Promoting gender-responsive policies, scholarships, mentorship programmes, inclusive learning environments, and equal career opportunities is essential for maximizing available human potential. Diverse participation enhances creativity, strengthens innovation systems, and improves the relevance of scientific and technological solutions by incorporating broader perspectives and experiences (UN Women, 2020; UNESCO, 2015).

6.4 Supportive Policy and Institutional Frameworks

Strong policy and governance structures provide the foundation for sustainable capacity development. Governments play a critical role in establishing national strategies for science, technology, innovation, research funding, education reform, and digital transformation (UNCTAD, 2021; OECD, 2023).

Effective policies should promote investment in research and development, strengthen higher education institutions, encourage private-sector participation, and create environments that support innovation. Institutional reforms are also required to improve research management, collaboration, accountability, and knowledge transfer (National Academies of Sciences, Engineering, and Medicine, 2017; WIPO, 2021).

6.5 Partnerships, Monitoring, and Sustainable Financing

Capacity building is strengthened through collaboration among governments, academic institutions, industries, international organizations, and development partners. Strategic partnerships enable knowledge exchange, resource mobilization, technology transfer, and sharing of successful practices. University-industry partnerships are particularly important for translating research outputs into practical innovations and strengthening national innovation systems (National Academies of Sciences, Engineering, and Medicine, 2017; UNCTAD, 2021).

Continuous monitoring and evaluation are essential for measuring progress, identifying weaknesses, and improving programme effectiveness. Evidence-based evaluation approaches help institutions determine whether capacity-building interventions are achieving intended outcomes and contributing to sustainable development objectives (Patton, 2015).

Furthermore, sustainable financing mechanisms are necessary to maintain capacity-building initiatives beyond short-term project cycles. Long-term investment in education, research infrastructure, innovation systems, and human development remains fundamental to achieving lasting impact and strengthening national scientific and technological capabilities (UNESCO, 2015; World Bank, 2017).

7. Global Case Studies and Lessons in Capacity Building for Inclusive and Sustainable Development

Successful capacity-building initiatives across different regions demonstrate that sustainable development outcomes are strongly influenced by investments in human capital, institutional strengthening, innovation systems, and inclusive technology access. To enable systematic comparison, each case below is analysed using a consistent structure, context, intervention, mechanism, outcomes, limitations, and transferable lessons, and is interpreted against the three-level conceptual framework introduced in Section 2 (UNDP, 2008; UNCTAD, 2021).

7.1 India's Aadhaar Digital Identity System

Context: Prior to Aadhaar, an estimated several hundred million Indians, disproportionately the rural poor, lacked reliable proof of identity, which excluded them from banking, welfare, and public services.

Intervention: The government developed a nationwide biometric digital identity platform assigning a unique identification number to residents, linked to fingerprint and iris data.

Mechanism: Aadhaar functioned as shared digital infrastructure (an institutional-level, Innovation Systems intervention) that other public and private systems, banking, subsidy disbursement, mobile registration, could plug into, rather than a standalone application.

Outcomes: The platform enhanced citizens' ability to access government services, social support programmes, and financial systems, and is widely credited with reducing leakage in direct benefit transfers (ITU, 2022; Broadband Commission for Sustainable Development, 2023).

Limitations: Digital identity systems of this scale raise significant data protection, privacy, cybersecurity, and exclusion risks; individuals lacking biometric readability or digital access risk exclusion from the very services the system was meant to extend (UNESCO, 2021).

Lessons for developing countries: Large-scale digital infrastructure requires institutional capacity, regulatory frameworks, and public awareness alongside the technology itself; digital transformation pursued as a purely technical exercise, without the Capability Approach's attention to who is excluded, can reproduce the inequalities it aims to solve.

7.2 Africa Centres of Excellence and Research Capacity Development

Context: African higher education institutions have historically faced fragmented postgraduate training capacity and weak regional research specialisation, limiting the continent's ability to generate locally relevant scientific solutions.

Intervention: The World Bank-supported African Centres of Excellence (ACE) initiative funds selected universities to develop specialised postgraduate and research capacity in science, technology, engineering, agriculture, and health disciplines (World Bank, 2017).

Mechanism: Funding is tied to regional collaboration requirements and performance benchmarks, creating incentives for institutions to specialise and to serve students from neighbouring countries rather than duplicating generalist programmes.

Outcomes: Participating centres have expanded postgraduate enrolment, strengthened research infrastructure, and developed international partnerships, contributing to Africa's capacity to generate locally relevant solutions to development challenges (UNESCO, 2015; UNCTAD, 2021).

Limitations: Centres remain heavily dependent on donor and government financing; sustainability beyond the initial funding cycle, and equitable access for students from the poorest institutions, remain open challenges.

Lessons for developing countries: Performance-linked regional funding can accelerate specialisation and collaboration, but exit strategies and domestic co-financing must be built in from the outset to avoid capacity loss when donor funding cycles end.

7.3 Africa Centre of Excellence in Future Energies and Electrochemical Systems (ACE-FUELS), Nigeria

Context: Nigeria's energy sector faces persistent shortages of specialised expertise in renewable energy and electrochemical systems research, constraining the country's capacity to diversify its energy base.

Intervention: ACE-FUELS, hosted at the Federal University of Technology Owerri, provides postgraduate training, professional development, and applied research opportunities targeted at energy challenges in Sub-Saharan Africa.

Mechanism: The centre combines postgraduate curricula with structured partnerships linking universities, industry, and international collaborators, functioning as a sector-specific node within the broader national innovation system.

Outcomes: The centre has developed specialised expertise and research networks in energy technologies, illustrating how sector-focused centres can build depth in strategic technology areas (National Academies of Sciences, Engineering, and Medicine, 2017; UNCTAD, 2021).

Limitations: As a single-institution centre, its reach is geographically and numerically limited relative to national skills demand, and replication to other strategic sectors requires financing and institutional capacity that are not yet guaranteed.

Lessons for developing countries: Specialised research centres are most effective as one node in a wider system; scaling their impact nationally requires deliberate replication strategy rather than reliance on a single flagship institution.

7.4 Rwanda's Digital Literacy and Technology Education Initiatives

Context: Rwanda set a national ambition to become a knowledge-based, digitally enabled economy despite starting from a low base of digital infrastructure and teacher digital competency.

Intervention: The government integrated digital skills into the education curriculum, invested in teacher training, and expanded access to technological resources and devices in schools.

Mechanism: The initiative paired infrastructure investment with parallel investment in curriculum reform and teacher capacity, an explicit attempt to build human capital and institutional readiness simultaneously rather than sequentially.

Outcomes: Digital literacy and technology-oriented human capital expanded across the education system, supporting broader participation in the digital economy (European Commission, 2020; OECD, 2018).

Limitations: Rural-urban disparities in device access and connectivity, and the pace at which teacher competency can be upgraded at scale, continue to constrain uniform national impact.

Lessons for developing countries: Technology adoption in education fails when infrastructure is prioritised over teacher training and curriculum reform; Rwanda's experience shows these must be sequenced together.

7.5 Kenya's M-Pesa Mobile Financial Technology Innovation

Context: A large proportion of Kenya's population, particularly outside major urban centres, lacked access to formal banking services prior to the mid-2000s, despite widespread mobile phone ownership.

Intervention: A telecommunications operator launched a mobile-money platform allowing users to store, send, and receive money via basic mobile phones without requiring a bank account.

Mechanism: The innovation exploited existing mobile network infrastructure and agent networks rather than requiring new physical banking infrastructure, and was supported by a permissive early regulatory environment that allowed the model to scale before being formalised.

Outcomes: M-Pesa expanded access to financial services among populations previously excluded from conventional banking and became a widely cited model of locally developed, contextually appropriate innovation (ITU, 2022; UNCTAD, 2021).

Limitations: Replication elsewhere has been uneven where regulatory environments were less permissive or where agent-network density could not be achieved, indicating that the model's success was partly context-specific rather than purely technological.

Lessons for developing countries: Locally developed solutions that build on existing infrastructure and behaviour patterns, supported by adaptive regulation, can achieve inclusion outcomes that imported models often cannot; the enabling regulatory environment was as important as the technology itself.

7.6 Cross-Case Lessons from Global Capacity-Building Experiences

Read together, the five cases demonstrate several common success factors: strong government commitment and policy support; investment in education and research capacity; collaboration among academia, industry, and government; development of locally relevant technologies; expansion of digital infrastructure; continuous skills development; and emphasis on inclusive participation.

A comparison across cases also reveals a recurring pattern relevant to the theoretical framework in Section 2: the cases that achieved outcomes across all three levels, individual skills (Aadhaar's and Rwanda's training components), institutional systems (ACE's regional financing model, M-Pesa's regulatory adaptation), and inclusive access (M-Pesa's reach to the previously unbanked), proved more resilient than interventions addressing only one level. Conversely, each case's limitations, exclusion risk in Aadhaar, financing dependency in the ACE initiatives, uneven scale in ACE-FUELS, rural-urban gaps in Rwanda, and uneven replicability of M-Pesa, trace back to a level of the framework that received comparatively less attention during design. These lessons indicate that capacity building is most effective when it deliberately combines technological advancement with institutional and inclusion-focused design from the outset, rather than treating the latter two as add-ons (UNDP, 2008; UNESCO, 2015; UNCTAD, 2021).

8. Challenges, Contradictions, and Future Directions for SET Capacity Building

Despite the recognized importance of science, engineering, and technology capacity building, significant barriers continue to limit its contribution to inclusive and sustainable development, particularly in developing countries. These challenges are associated with limited research investment, inadequate infrastructure, weak innovation ecosystems, skills shortages, unequal access to technology, and institutional constraints (UNESCO, 2015; UNCTAD, 2021).

8.1 Limited Funding for Research and Innovation

Insufficient investment in research and development remains one of the major constraints affecting scientific advancement. Many institutions lack adequate funding for laboratories, research equipment, postgraduate training, and innovation activities. Limited financing reduces research productivity and weakens the ability of countries to develop indigenous technologies and participate effectively in global innovation systems (UNESCO, 2015; World Economic Forum, 2019). Addressing this challenge requires increased government investment, stronger private-sector participation, competitive research funding mechanisms, and international collaboration (UNCTAD, 2021; OECD, 2023).

8.2 Inadequate Infrastructure and Digital Connectivity

Effective SET development requires reliable infrastructure, including laboratories, internet connectivity, electricity supply, and modern learning facilities. However, many developing regions continue to experience infrastructure deficits that limit access to scientific resources and technological opportunities (World Bank, 2017; ITU, 2022). Digital inclusion strategies that combine infrastructure development with affordability and digital skills training are particularly important for underserved populations (Broadband Commission for Sustainable Development, 2023; ITU, 2022).

8.3 Brain Drain and Loss of Skilled Professionals

The migration of highly skilled scientists, engineers, and researchers to countries with better professional opportunities remains a major challenge. Brain drain reduces institutional capacity, weakens national innovation systems, and limits the ability of developing countries to sustain scientific advancement (UNESCO, 2015). Strategies such as improved research funding, attractive career pathways, international collaboration, and opportunities for professional development are necessary to retain skilled professionals and encourage knowledge exchange (UNCTAD, 2021; World Bank, 2017).

8.4 Skills Mismatch and Curriculum Challenges

Rapid technological changes have created gaps between educational outcomes and labour market requirements. Many graduates lack practical skills, digital competencies, entrepreneurship abilities, and industry-relevant experience needed in emerging knowledge economies (OECD, 2018; World Economic Forum, 2019). Greater alignment between education systems and labour market needs is essential for developing adaptable and future-ready professionals (European Commission, 2020; OECD, 2023).

8.5 Gender and Social Inequalities

Persistent inequalities continue to limit participation in SET, particularly among women and disadvantaged communities. Social barriers, limited mentorship opportunities, and unequal access to educational resources restrict diversity within science and engineering fields (UN Women, 2020; UNESCO, 2017; Jackson et al., 2022).

8.6 Critical Analysis: Contradictions, Sustainability, and Financing Limitations

The preceding sections, and the case studies in Section 7, point to recurring contradictions that a purely descriptive account would understate. First, there is a persistent donor-dependency contradiction: initiatives such as the African Centres of Excellence programme demonstrably build capacity, yet remain structurally reliant on external financing whose continuation is not guaranteed, raising the question of whether such programmes build durable national capacity or a form of capacity that persists only as long as external funding does. Second, technology-led interventions such as Aadhaar illustrate an inclusion-exclusion contradiction: platforms designed to expand access can simultaneously create new forms of exclusion for those unable to meet their technical or biometric requirements, meaning that digital inclusion strategies must be evaluated on who is left out, not only on aggregate uptake.

Third, the review identifies a scale-versus-depth contradiction in specialised research centres such as ACE-FUELS: deep, sector-specific expertise is most efficiently built in concentrated centres of excellence, yet national skills demand requires broad coverage that concentrated models are not designed to deliver, implying that capacity-building portfolios need a deliberate mix of concentrated and distributed interventions rather than reliance on either alone. Fourth, the M-Pesa case illustrates that regulatory permissiveness that enables innovation to scale quickly can create governance gaps that must later be retrofitted, meaning that the sequencing of innovation and regulation, not merely their eventual coexistence, is itself a design choice with consequences.

Financing limitations compound each of these contradictions. Much of the capacity-building literature reviewed here, and several of the case studies, describe project-cycle financing (typically three to seven years) applied to outcomes, institutional research capacity, curriculum reform, workforce pipelines, that require a decade or more to mature. This mismatch between financing horizons and capability-building timelines helps explain why infrastructure and training outputs are frequently reported while longer-term institutional and innovation-system outcomes are less consistently documented. Future capacity-building design should therefore treat financing duration as a primary variable, not a background constraint, and should build domestic co-financing and revenue-generation mechanisms into programme design from inception rather than as a late-stage sustainability plan.

8.7 Future Strategic Directions

To strengthen SET capacity for sustainable development, future efforts should focus on:

- increasing investment in STEM education, research, and innovation, with financing horizons matched to capability-building timelines;
- strengthening university-industry partnerships and diversified, hybrid governance models for innovation ecosystems;
- promoting digital transformation and technology access while embedding data protection, privacy, and exclusion safeguards from the design stage;
- supporting entrepreneurship and technology commercialization;
- encouraging regional and international collaboration with explicit domestic co-financing and exit strategies;
- developing policies that promote inclusive participation, particularly for women, rural populations, and persons with disabilities; and
- establishing long-term monitoring systems, with defined indicators, for capacity-building programmes.

These strategies require coordinated action among governments, educational institutions, industries, research organizations, and development partners. Strengthening innovation ecosystems through integrated investments in human capital, infrastructure, governance, and knowledge systems is essential for achieving sustainable development outcomes (UNCTAD, 2021; UNESCO, 2021).

9. Policy Implications and Recommendations

Based on the reviewed evidence and the contradictions identified in Section 8.6, the recommendations below move beyond general directional statements to specify, for each stakeholder group, the responsible actor, a concrete action, an indicative timeframe, the resources required, and a measurable indicator of progress. Effective policies should address human capital development, research systems, digital transformation, innovation ecosystems, and inclusive participation to ensure that technological advancement contributes to sustainable development (United Nations, 2015; UNCTAD, 2021). Table 1 outlines a coordinated, multi-stakeholder roadmap to strengthen science, technology, and innovation (STI) for sustainable development. Governments are tasked with laying the foundation through increased R&D funding, a national STI strategy, and expanded digital

infrastructure. Higher education institutions must modernize curricula, boost postgraduate research, and formalize partnerships with industry and government.

Table 1: STI Recommendations for Sustainable Development

Stakeholder	Recommended Action	Timeframe	Required Resources	Measurable Indicator
Governments	Increase public R&D funding	Short-term (1–2 yrs), sustained	National R&D budget; co-financing	R&D spending → 1% of GDP (AU target)
Governments	Enact national STI strategy	Within 18 months	Policy unit; consultations	Approved strategy with costed plan
Governments	Expand digital infrastructure with data safeguards	Medium-term (3–5 yrs)	Capital; PPPs	Broadband penetration ↑; urban-rural gap ↓
Higher Education	Update SET curricula for emerging skills	1–3 yrs	Review committees; industry boards	Programmes revised with industry input; employability ↑
Higher Education	Strengthen postgraduate research capacity	3–5 yrs	Grants; labs; scholarships	Postgrad enrolment ↑; research output ↑
Higher Education	Formalize industry-government partnerships	Within 2 yrs, ongoing	TTOs; partnership frameworks	Active tripartite agreements & joint projects
Industry	Commercialize technologies	2–4 yrs	R&D co-investment; venture capital	Technologies commercialised from collaborations
Industry	Co-design curricula & training	Within 1 yr, ongoing	Staff time; internships	Curricula co-designed; internship placements
Industry	Offer internships & professional development	Ongoing, annual review	Internship budgets; mentors	Annual placements; post-placement employment rate
Development Orgs	Fund capacity-building with co-financing & exit plans	3–5 yrs per cycle	Grants; co-financing agreements	Programmes with domestic co-financing at design
Development Orgs	Facilitate international knowledge exchange	Ongoing	Exchange budgets; convening	Cross-country collaborations & events per year
Researchers	Conduct multidisciplinary research on local issues	Ongoing	Research time; networks	Multidisciplinary publications; applied outputs
Researchers	Engage in knowledge transfer & outreach	Ongoing	Outreach programmes; public engagement	Community engagement & transfer activities per year

Collectively, these actions can create stronger innovation ecosystems capable of supporting inclusive and sustainable development. Achieving this vision requires sustained commitment to human capital development, institutional strengthening, equitable access to technology, and evidence-based policy implementation, monitored against the indicators above rather than treated as a one-time policy statement (United Nations, 2015; UNCTAD, 2021).

10. Conclusion

Capacity building in science, engineering, and technology represents a fundamental pathway for achieving inclusive and sustainable development. While scientific advancement and technological innovation provide powerful tools for addressing global challenges, their impact depends on the availability of skilled human

resources, strong institutions, effective innovation systems, and inclusive policies, the three levels of the conceptual framework applied throughout this review.

This review highlights that successful SET capacity building requires an integrated approach combining education reform, workforce development, research strengthening, digital inclusion, innovation support, strategic partnerships, and sustainable financing. The case evidence in Section 7 and the critical analysis in Section 8 demonstrate that countries accelerate development outcomes when technological advancement is deliberately aligned with institutional design and social inclusion from the outset, rather than when inclusion and sustainability are addressed as afterthoughts.

However, challenges including inadequate funding, infrastructure limitations, brain drain, skills gaps, and social inequalities continue to restrict progress, particularly in developing regions, and the financing-horizon mismatch identified in Section 8.6 remains a structural obstacle to converting short-term projects into durable capacity. Addressing these challenges requires coordinated action among governments, universities, industries, international organizations, and communities, guided by the stakeholder-specific, time-bound recommendations proposed in Section 9.

Ultimately, science, engineering, and technology should be viewed not only as instruments of economic advancement but also as platforms for improving human well-being, protecting the environment, and promoting equitable development. Sustained investment in SET capacity building, evaluated against explicit indicators and matched to realistic financing horizons, will therefore remain essential for enabling societies to respond effectively to current and future global challenges while achieving the aspirations of the Sustainable Development Goals.

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