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STEM for Sustainable Development in Pakistan: Innovative Practices and Future Prospects

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Abstract
In Pakistan, STEM education is important for fostering innovation and new improvements for sustainability. This research used a mixed-method approach by surveying 100 teachers with closed-ended questions and doing semi-structured interviews with 30 teachers. The results show that, under adverse conditions of poor infrastructure, low investment, and slack policy implementation, creative approaches like project-based learning, digital labs, and inexpensive science kits are vital for STEM education's effectiveness. The results suggest that major policy changes are necessary and that new investment would be required along with teacher training, enhanced technology integration, and improved industry–academy collaboration. These pointers provide a coherent strategy to promote STEM education in Pakistan and align it with emerging sustainability benchmarks globally.

Keywords: STEM Education, Sustainability, Sustainable Development Goals, Education for Sustainable Development, Innovation, Pakistan.

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1. Introduction

In the modern age, the education systems of the world have begun to focus on the imparting of knowledge, skills, attitudes, and competencies to learners for the resolution of complex social, technological, and environmental problems. One of the best possible ways of achieving these objectives is the adoption of Science, Technology, Engineering, and Mathematics (STEM). As stated by Marginson et al. (2013), STEM education promotes critical thinking and creative thinking,

problem solving, and collaboration which is critical for not only the attainment of future skills but for the attainment of sustainable development. The incorporation of STEM into the curriculum also directly addresses the United Nations Sustainable Development Goals (SDGs). For instance, STEM education addresses SDG 4 (to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all), SDG 9 (to build resilient infrastructure, foster inclusive and sustainable industrialization, and promote innovation), and SDG 13 (Climate action). STEM education therefore promotes equitable learning opportunities together with technological advancement and environmental sustainability. As Bybee (2013) and Thibaut et al. (2018) point out, countries like Finland, Singapore, and South Korea have incorporated STEM education into their national education policies to increase innovation in their economies. For instance, Singapore puts considerable effort toward the advancement of advanced labs and fully integrated STEM teacher training, both of which form the basis of the country's innovation model (Tan et al., 2019). These cases from other countries highlight how STEM education can equip the younger generation with the knowledge and skills needed to tackle almost any modern-day problem—such as climate change, energy, and urbanization.

STEM education in Pakistan has yet to accomplish full integration. Teachers still have some gaps that limit the understanding of importance of STEM education and its implementation. ASER Pakistan in the year 2020 mentioned that the country’s education and STEM education deficiency problem stems from lack of STEM curricula, poorly trained teachers, and deficient science laboratories. The lack of central mentoring the key STEM components emergent technologies, instructional thinking systems, problem-centric frameworks, and foundation e-learning systems, is a sizeable problem (Rehmani, 2019). Moreover, the gaps and inequalities in country-city and city-country STEM education are

inequitable. STEM education gaps and inequities in Pakistan are inequitable. Primary and secondary schools/elite institutions in Pakistan are beginning to introduce STEM citizenship programs, albeit on a limited scale, such as robotics clubs, coding classes, and even renewable energy initiatives. Unfortunately, such programs are almost non-existent in institutions which have the highest enrollment rates. Ibrees and Jabeen, 2021. Other deficits affecting Government institutions include lack of laboratory facilities, infrastructural facilities such as science laboratories and internet access. UNESCO, 2016. These systemic shortcomings undermine not only Pakistan's competitive posture in the context of the SDG 4, but also Pakistan's ability to sustain a productive, skilled future workforce.

1.1. Problem Statement

While global literature on STEM education highlights its potential for advancing sustainability and innovation, limited research has explored the intersection of STEM and sustainable development within the Pakistani context. Existing studies are largely descriptive or policy-oriented and often overlook the lived realities of teachers and the practical challenges they face in implementing STEM practices. The lack of context-specific, empirical evidence constrains policymakers, educators, and institutions from designing targeted and effective strategies for STEM integration. To address this gap, the present study investigates teachers' perspectives on innovative practices, barriers, and prospects of STEM education in Pakistan, offering insights that can inform both national policy and classroom practice.

1.2. Purpose of the Study

This study aims to examine innovations in STEM education and their potential contributions to sustainable development in Pakistan. A concurrent embedded mixed-method design was employed, incorporating a survey of 100 teachers

alongside in-depth interviews with 30 teachers, to capture both broad perceptions and detailed practices of STEM education. The research further seeks to explore the sociocultural and theoretical constraints that hinder the integration of STEM education, while also considering pragmatic pathways for aligning STEM initiatives with Pakistan's educational policies and the broader Sustainable Development Goals (SDGs).

1.3. Research Questions

This study is guided by the following research questions:

1) What innovative STEM practices are currently used in Pakistani schools?
2) What challenges do teachers face in integrating STEM for sustainability?
3) What are the prospects of STEM in advancing sustainable development in Pakistan?

1.4. Significance of Study

This research has the almost priceless benefit of adding to the almost nonexistent literature regarding TRMs on STEM and sustainability in Pakistan and talking about the teacher's perspective which is often absent in more state-centered works. It also helps in the identification of innovative practices and successful scalable models in diverse educational contexts. Lastly, the evidence generated in this matter is bound to serve the STEM sustainability within the framework the STEM policymakers, curriculum developers, and teacher educators for advocacy purposes. This helps the policymakers to integrate the National Educational Reforms with the Sustainable Development Goals and strengthen Pakistan's global position regarding knowledge, innovation, and environmentally sustainable investments. The research in question will serve teacher training programs in addition to advancing foundational policy directions with the goal of

equity in technological and sustainable development of the country. This introduction highlights the significance of STEM education for the purpose of sustainable development at both the global and national levels. It places the ongoing challenges facing Pakistan in the context of this larger narrative, outlines the void in the existing literature, and prepares the ground for an evidence-based study that seeks to inform both policymakers and practitioners.

2. Conceptual Framework

2.1. STEM Education

STEM education encompassing Science, Technology, Engineering, and Mathematics represents an explicit curricular and pedagogical commitment to transcending disciplinary boundaries and fostering inquiry through authentic, real-world challenges. As framed by Bybee (2013), STEM is not limited to preparing future specialists but aims to cultivate adaptive dispositions by linking theoretical knowledge with practice in socially constructive ways. The integration of disciplinary perspectives reflects the recognition that natural, technological, and social phenomena are rarely experienced in isolation, and that an interdisciplinary instructional framework offers both efficiency and substantive educational payoff.

Globally, the scope of STEM education continues to expand, with policymakers and educators positioning it as a driver of emerging knowledge systems, technological paradigms, and innovation economies (Marginson et al., 2013). Beyond equipping learners with skills for targeted labor markets, STEM pedagogies also create conditions for inclusive and resilient economic growth at both macro and micro levels. Instructionally, STEM has come to encompass project-based learning in authentic laboratory and prototype settings, robotics, coding in both block- and text-based formats, renewable energy simulations, and the strategic integration of information and communication technologies.

In developing economies such as Pakistan, the STEM proposition extends beyond issues of efficiency and innovation to address structural concerns. It provides pathways for competency development that can realign national certification frameworks with sustainability-informed global standards, thereby enabling individuals and institutions to contribute meaningfully to both local development and international sustainability goals.

2.2. Sustainability and SDGs

The 2030 Agenda for Sustainable Development adopted in 2015 has shifted the focus for multilateral policies worldwide. Out of the 17 Sustainable Development Goals (SDGs), three—SDG 4 (Quality Education), SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action)—recognize the crucial importance of education for the building of inclusive societies, scientific and technological advancement, and preparing learners to cope with climate change (UNESCO, 2020). Among these SDGs, SDG 4 deals with the equity of education and instructive freedom in the lifetime frame, SDG 9 promotes reinforced infrastructure and innovation driven growth, and SDG 13 stresses climate and environmental education integrated at all levels.

As a response, there is a growing trend in integrating the principles of sustainability into designed changes to curricula, methods of teaching, and learning assessment in many countries. The practicality of STEM education coupled with the global change offers students the opportunity to engage in hands-on learning through inquiry projects focused on the design of systems such as renewable energy, water-conserving, waste-reduction, and engineering problem-solving systems to sustain the sustain. These experiences enhance scientific and technological literacy, eco-literacy, responsible citizenship, ethical systems, and critical systems thinking which are essential for sustaining the future (Beier et al. 2019).

In Pakistan, however, the integration of sustainability values into STEM curricula has progressed only modestly. Many syllabi remain anchored in outdated content, while policy measures often lack coherence and consistent enforcement (Rehmani, 2019). For Pakistan to fully harness the transformative potential of STEM, systematic alignment between ongoing national educational reforms and the SDGs is imperative. Purposeful STEM instruction must therefore be placed at the heart of the country's strategy to achieve sustainable development.

2.3. Education for Sustainable Development (ESD) and STEM

Education for Sustainable Development (ESD), as advanced by UNESCO, represents a comprehensive paradigm that equips learners with the knowledge, values, and competencies needed to construct a sustainable future. Unlike conventional environmental education, ESD interweaves ecological, social, economic, and cultural dimensions of sustainability across curricular, co-curricular, and extra-curricular experiences (UNESCO, 2016). Its normative orientation positions education as a transformative tool, enabling individuals to make ethically informed decisions and to act responsibly at scales ranging from the local community to the global sphere.

The ESD framework provides constructive scaffolding for STEM education, as both share epistemic and civilizational goals: critical inquiry, problem-solving, systems-oriented understanding, and innovative advancement. When integrated into STEM pedagogy, ESD mobilizes scientific and technological literacy toward addressing pressing sustainability challenges such as climate change, resource management, and social equity (Biasutti & Frate, 2017). For example, the development of a low-cost solar-powered water purification system within a STEM learning community not only illustrates the applied relevance of thermodynamics, microbiology, and materials science but

also cultivates eco-literacy, ethical awareness, and social responsibility.

Pakistan stands to benefit tremendously from the educational reform and national development that integrating ESD into the STEM curriculum offers. Such versatile integration would allow learners to associate disciplinary content with complex and critical socio-economic issues, including but not limited to, energy scarcity, degradation of the environment, and growing gaps in digital equity. Therefor the integration of ESD and STEM would significantly enhance the quality of education as well as contribute to development in the country.

2.4. Theoretical Framework

This study utilizes three interrelated theoretical frameworks in integrating STEM within sustainability paradigms: constructivist epistemologies, inquiry-based learning (IBL) models, and integrated technology in 'instructional' design (TD models). Constructivist frame, theory and pedagogy, live the learner in a passive and sedentary status and therefore learning is contextualized in and around phenomena (Paiget, 1970; Vygotsky, 1978). STEM education pedagogy at its best is 'Constructivist pedagogy' which stems at engaging the learner actively in real-life authentic experiments and parallel real-life and theoretical collaborative constructive problem solving and frequent redefinition of the design and redesign of the environmental problems. These practices blend with development-oriented curricula which seek to push learners from lower order level of recall to higher order thinking level of application to real world, urgent and complex global problems.

IBL- Inquiry Based learning has a central role in stimulating intellectual inquiry and metacognition by placing learning within projects or problem-centered investigations. In the context of STEM, it relates to designing energy-efficient structures or digital systems for resource optimization (Hmelo-Silver et al., 2007). IBL develops not only cognitive skills, but also persistence, creativity,

and ethical stewardship of socio-technical and socio-ecological systems.

Technology Integration frameworks like TPACK and SAMR aid in the integration of teaching methods and the use of digital resources. Their impact becomes acute in education of STEM where digital simulations, interactive tools, and data analytics enhance engagement and broaden participation (Koehler & Mishra, 2009). In developing countries like Pakistan, intentionally designed frameworks of TEL, virtual STEM labs, and portable STEM kits overcome infrastructural barriers and promote sustainable education.

3. Literature Review

The education system of Finland gives equal attention to the learning by inquiry approach and cross- disciplinary integration of subjects. This means that mathematics, science, arts, and social studies are taught in an integrated framework which is close to the learner's environment, for example, regional water issues. It enables students to ask productive questions and apply relevant literacies to answer them. As co-researchers, he and she design and implement experiential projects and empirical studies which aim to fulfill curricular requirements while sustaining global competencies. It enables small, and sufficiently trained, staff to teach multi-age classes and replace standardized tests with formative, peer-referenced assessments, which makes the system sustainable financially.

Learners engage in outcome-driven activities devise solar energy prototypes, code autonomous bots, and prototype eco-circular textiles. Central to the philosophy are student agency, a high trust teaching profession, and universally equitable infrastructure availability (Niemi, Toom, & Kallioniemi, 2016).

Singapore, in contrast, operates under a purposefully sequenced curriculum, intentionally aligned with national innovation and economic projections.

Landmark STEM schools, fabric and scanning labs, and purposeful industry axle all work synchronously to cultivate futurist competencies (Tan & Leong, 2014). Central in the narrative are sustainability vectors—urban hydro-gardens and living lab ecosystems populating "smart nation" narratives.

Within the United States, diverse ecosystems of makers and betroffen initiative sustain a project-based ethos echoed in the Next Generation Science Standards. Federal and state apparatus underwrites STEM Challenge pathways, funded micro-credentialing app labs, and district-industry co-op consortia. The STEM 2026 vision straightforwardly asserts an aspirational compact for equitable, transdisciplinary, futures-oriented learning, with sustainability imperatives firmly front and center (U.S. Department of Education, 2016).

The global experiences highlight that innovative STEM practices are characterized by:

- Integration across disciplines.
- Alignment with national priorities.
- Strong teacher training systems.
- Partnerships between schools, universities, and industries.

These lessons are crucial for countries like Pakistan, which is still in the early stages of STEM adoption.

STEM instruction is now a defining mechanism for embedding sustainability across global educational systems. In diverse settings, teachers leverage an interdisciplinary STEM approach to foster eco-literacy by deepening students' understanding of ecological systems alongside the human dimension of ecological footprints. Practical activities, whether in laboratories, makerspaces, or outdoor field sites steer learners toward core sustainability domains, including the design of renewable-energy solutions, the valorization of waste, the conservation of freshwater resources, and the development of climate-adaptive

and climate-mitigation techniques.

Within European educational models, for instance, project-based STEM curricula engage learners through the design, fabrication, and deployment of functional prototypes that address authentic socio-environmental challenges. Conscripting students to build photovoltaic arrays, to engineer low-cost drip-irrigation systems, or to program autonomous sensing platforms for ambient air and water-quality surveillance, such curricula intertwine the acquisition of technical skills with the internalization of sustainability principles, thereby situating students' theoretical studies in the immediacy of contemporary environmental conditions (Beier et al., 2019).

Concurrently, STEM curricula are a critical incubator for emergent green technologies. Engineering and technological pathways within schools and universities the world over privilege innovation in photovoltaics, automated demand-response smart grids, and precision protocols within agroecosystems (El-Deghaidy et al., 2017). Not only are these studies calibration for future green-employment markets, but such linkage fortifies the connective tissue between academic sanction and regional innovation economies. By embedding sustainability as thematic core, these pedagogies inventory systems, assess multiple, often competing, performance indices, and innovate resilient, scalable artefacts (Bybee, 2013).

STEM instruction is assuming an increasingly strategic role in Pakistan's education reform agenda, notably as efforts mount to realign national systems with Sustainable Development Goal (SDG) benchmarks. Within this framework, several salient programs have been instituted across policy and institutional dimensions:

1) The Higher Education Commission (HEC) leverages targeted funding mechanisms to bolster STEM capacity, including grants for exploratory

research, comprehensive faculty training packages, and state-supported technology incubation hubs. The National Research Program for Universities (NRPU), for instance, prioritizes projects that promise innovative contributions to STEM (HEC, 2021).

2) The newly enacted Single National Curriculum (SNC) purports to weave scientific and technological literacies into every compulsory tier of schooling. Implementation pathways, though, have registered inconsistencies; surveillance reports cite a persistent neglect of inquiry-oriented pedagogies that are regarded as instrumental to authentic STEM engagement (Hoodbhoy, 2020).
3) Concomitantly, the Ministry of Science and Technology has co-commissioned a sequence of STEM-oriented experimental schools, augmented by nationwide mathematics and robotics Olympiads. These initiatives seek to galvanize early interest and analytical competencies among the youth talent pool (Ministry of Science and Technology, 2019).
4) Complementing state efforts, several non-governmental and private enterprises – including Teach for Pakistan and Knowledge Platform – have rolled out blended digital platforms, immersive coding domestic courseware, and modular project-centric STEM experiences, thereby embedding the discipline into metropolitan and peri-urban classrooms with notable efficiency.

Despite the aggregate progress represented by these interventions, systemic impediments remain pronounced. Persistent funding gaps, obsolescence in infrastructural provisioning, and the chronic mismatch between curricula and professional development pathways continue to stymie the depth and durability of STEM outcomes.

Despite increasing acknowledgment of STEM's capacity to advance sustainable development in Pakistan, the program continues to encounter a series of interrelated impediments:

1) Absence of Laboratories and Support Infrastructure: Basic scientific educational facilities, such as fully equipped laboratories, functioning computer laboratories, and reliable internet connections, are notably absent in a significant proportion of rural schools, impeding the delivery of effective STEM pedagogy (Khalid & Khan, 2019).
2) Persistent Digital Inequity: Although elite private schools in urban centers are gradually adopting robotics and coding modules, the remaining public and rural institutions experience a persistent lag in both material provisions and internet connectivity; these gaps were underscored and intensified by the disruptions of the COVID-19 pandemic (Mahmood, 2021).
3) Deficient Teacher Professional Development: Pre-service and in-service teacher education predominantly privileges conventional didactic approaches, neglecting the methodologies central to inquiry, project-based investigation, and technology integration; as a consequence, educators frequently express insufficient self-efficacy concerning STEM instruction (Rehmani, 2019).
4) Curricular Inflexibility: The prevailing curricula are anchored in rote memorization and conformity, sidelining higher-order cognitive skills such as analytical reasoning and creative inquiry, thereby constraining the capacity of STEM instruction to act as a leverage point for sustainable solutions (Hoodbhoy, 2020).
5) Disjunction between Policy and Practice: Although national strategic frameworks enunciate a commitment to STEM education, execution

remains stymied by entrenched bureaucratic inertia and fragile mechanisms of inter-level coordination among federal and provincial administrative bodies (HEC, 2021).

These interlocking obstacles affirm the imperative of a multidimensional reform agenda, predicated upon strategic enhancements of educational infrastructure, comprehensive capacity-building for educators, and substantive and flexible re-engineering of curricular contents and practices.

A comprehensive examination of the scholarly corpus indicates that international investigations have addressed the convergence of STEM education and sustainability in considerable depth, yet literature specific to Pakistan is markedly sparse. The predominant emphasis of the corpus resides in general science education, thereby offering insufficient attention to integrated STEM methodologies. Empirical inquiries that specifically inquire into the capacity of STEM to advance sustainable development within Pakistan, and that solicit the viewpoints of classroom practitioners, are exceedingly rare.

Apart from this, only fragmentary evidence exists about nationally representative findings on the adoption of innovative pedagogies within STEM classrooms, the preparedness of educators to implement integrative STEM approaches, and the contributions of STEM initiatives to the attainment of the Sustainable Development Goals. The present inquiry therefore seeks to furnish systematic evidence by means of structured surveys and semi-structured interviews administered to teachers across the country, thereby illuminating prevailing pedagogical patterns, salient obstacles, and prospective strategic pathways linking STEM to sustainable progress within the Pakistani educational landscape.

4. Methodology

4.1. Research Design

This investigation employs an integrated quantitative–qualitative strategy, enabling an empirically grounded comprehension of STEM pedagogy within the Pakistani educational context. The strategy's architecture leverages the strengths of both strands, permitting cross-validation whereby survey-generated statistics illuminate widespread tendencies and interview-derived narratives contextualize those tendencies within practitioners situated realities (Creswell & Plano Clark, 2018). The quantitative strand centers on a structured survey administered to a purposive sample of one hundred STEM instructors, soliciting evaluations of pedagogical innovation, encountered impediments, and perceived conditional requirements for sustainable curricular advancement. The qualitative strand contains semi-structured, iterative interviews with thirty of the same instructors, and their open-ended answers provide rich, longitudinal insights into the STEM teaching phenomenology. The integrated designs, complementary in purpose, deliver a synchronized, comprehensive payload of both generalizability and situated contextual interpretation, thus aiding in a compelling fusion of pedagogical practice.

4.2. Population

This study's target population encompasses STEM teachers in Pakistan. They deliver STEM content and understand classroom practices, systemic impediments, and future possibilities. Their insights would be invaluable. Participants in this research come from both public and private schools so as to enhance the diversity of the institutional settings.

4.3. Sample

To ensure feasibility and depth, the study relies on two complementary samples:

- Quantitative Sample: 100 teachers who will complete a structured survey questionnaire.
- Qualitative Sample: 30 teachers selected from the survey participants

for semi-structured interviews.

As documented in the literature, we estimate the sampling size to fall within the lower-class limit of 80, or the upper-class limit of 150 participants. Khalid and Khan 2019 offer no alternative estimates. A sample of 30 respondents should suffice in reaching saturation. No new themes should arise beyond this point. (Guest et al, 2006).

4.4. Sampling Technique

This study uses purposive sampling. This sampling technique is non-probability in nature, but it is justified since the study aims to have teachers with STEM teaching practices. The participants will be recruited from schools where STEM-related 'hands-on' activities, project-based learning, robotic clubs, or digital technology activities have already started. Purposive sampling guarantees that the respondents offer valuable information that is in line with the aims of the study (Etikan, Musa, & Alkassim, 2016).

4.5. Data Collection Tools

4.5.1.Survey Questionnaire

A structured Likert-scale questionnaire will be developed to capture teachers' perceptions of STEM education and sustainability. The questionnaire will include three main sections:

1) Demographics: Gender, teaching experience, subject area, school type (public/private).
2) Innovative STEM Practices: Items on project-based learning, digital technology use, interdisciplinary teaching, and student engagement.
3) Challenges and Prospects: Items on barriers (resources, training, curriculum) and perceived future opportunities for STEM in advancing sustainable development.

The Likert scale will range from 1 = Strongly Disagree to 5 = Strongly Agree.

Pilot testing will be conducted with 10 teachers to refine items for clarity and reliability.

4.5.2.Interview Guide

A semi-structured interview protocol will be designed to elicit in-depth insights. Guiding questions will include:

- How do you integrate STEM practices in your classroom?
- Can you share an example of an innovative STEM project you implemented?
- What challenges do you face in aligning STEM with sustainability?
- How do you see the future of STEM education in Pakistan in relation to sustainable development?

Interviews will last 30–40 minutes each and will be audio-recorded with participants' consent.

4.6. Data Analysis

4.6.1.Quantitative Analysis

The authors will calculate basic descriptive statistics on the data, including the distribution of frequencies, relative frequencies, means and standard deviations. Such analyses will value the general tendencies of teachers' perceptions and the distribution of teacher innovative practices and the challenges of innovative and non-innovative practices. For instance, the mean scores will suggest the analyzed levels of the agreement with the statements on STEM practices advocacy for sustainability. The authors will perform analyses with the help of tools like SPSS or Excel. Organizing the results will include presenting them in tables and graphs.

4.6.2.Qualitative Analysis

Interview transcripts will be analyzed using thematic analysis (Braun & Clarke, 2006). The process will include:

1) Familiarization: Reading transcripts multiple times.

2) Coding: Identifying meaningful segments of text (e.g., "lack of labs," "enthusiastic student response").
3) Theme Development: Grouping codes into categories such as "resource barriers," "teacher innovation," and "policy gaps."
4) Review and Refinement: Ensuring themes accurately reflect participants' voices.
5) Interpretation: Linking themes to research questions and the conceptual framework.

Complementing quantitative conclusions, thematic analysis will illuminate intricate experiences.

This research employs a pragmatic paradigm for analyzing sustainable innovative practices posed by STEM Education in Pakistan. The methodology integrates quantitative survey data from a sample of 100 teachers, alongside qualitative data from 30 interviews. Purposeful sampling for STEM education participants carefully ensured that the complexities of the issues were matched to quantitative surveys and qualitative interviewing. The validity and reliability of the researched outcomes is ensured through the ethical principles of conducting research alongside thorough and rich thematic descriptive analysis of the qualitative and quantitative data provided.

5. Findings

5.1. Survey Results (100 Teachers)

The survey results afforded a sweeping view of the invaluable insight held by the instructors concerning STEM-related innovation and sustainability practices and the implementation challenges within the classroom setting.

5.1.1.Innovative Practices in Classrooms

Most educators noted including at least some innovative practices related to STEM education. Typical practices included PBL (project-based learning) with

62% and the use of digital simulations and other forms of multimedia with 55% of the sample, and interdisciplinary or cross-disciplinary teaching with 40%. However, only 25% of respondents claimed to use robotics, coding or advanced STEM kits regularly.

Table 1: Reported Innovative STEM Practices by Teachers (n=100)

Innovative Practice	Percentage of Teachers Reporting Use
Project-based learning	62%
Digital simulations/multimedia tools	55%
Cross-disciplinary STEM integration	40%
Robotics/coding/STEM kits	25%
Sustainability-focused STEM projects	30%

The author's argument has merit; however, it appears that innovation is not always practiced at its most advanced degree. It is not uncommon for such activities to be elementary in character in relation to the existing infrastructure and training opportunities.

5.1.2.Perceptions of STEM's Role in Sustainability

Almost all survey respondents have a positive outlook regarding the contribution of STEM towards sustainable development. Approximately 78 percent of educators supported the idea that STEM promotes eco literacy and awareness of environmental issues, whilst 70 percent maintained that STEM equips students with problem solving skills essential for sustainability.

Table 2: Teachers' Perceptions of STEM and Sustainability

Statement	Agree/Strongly Agree (%)
STEM promotes eco-literacy and environmental awareness	78%
STEM develops critical problem-solving skills for sustainability	70%
STEM can prepare students for green jobs and industries	65%
STEM aligns with Pakistan's educational development goals	60%

The data suggest unanimity that STEM is an unutilized avenue for promoting

sustainability in Pakistan.

5.1.3.Challenges Faced

The respondents named various issues restricting them from fully executing STEM education. The highest ranked problems included the absence of laboratory spaces (72%), inadequate professional development (68%), and inflexible curricular frameworks (60%).

Table 3: Reported Challenges in Implementing STEM (n=100)

Challenge	Percentage of Teachers Reporting
Lack of laboratories and equipment	72%
Insufficient training/professional development	68%
Rigid curriculum focused on rote learning	60%
Limited digital access/internet facilities	55%
Heavy workload and large class sizes	48%

These findings highlight systemic gaps that must be addressed to realize the full potential of STEM education for sustainable development.

5.2. Interview Results (30 Teachers)

The insights gained from qualitative interviews were invaluable to capturing the teachers lived experiences barriers faced and opportunities they perceived towards STEM integration in the context of Pakistan.

5.2.1.Detailed Insights into Real Experiences

Educators recounted their efforts in implementing STEM into their teaching practices. Some mentioned successful student-led projects that focused on water purification, solar-powered devices, and waste management campaigns. Others focused on their challenges with limited resources, particularly in rural settings. One teacher stated:

“We want to do STEM projects, but without labs and materials, it becomes difficult. Sometimes we improvise with local materials, but it is not enough for deeper learning.”

5.2.2.Teachers' Voices on Barriers and Opportunities

Teachers have grown keenly aware of the recurring gaps in resource lack, scant policy support, and limited professional training components. Still, there is the opportunity of increasing enthusiasm among students, getting the attention of parents in urban schools, and having access to various digital tools.

One respondent remarked:

"Students are highly motivated when they see STEM linked to real-life issues like clean water or climate change. The challenge is we teachers are not fully trained to guide them in such projects."

6. Discussion

The research emphasizes the relationship between the barriers faced towards the implementation of STEM education in Pakistan, the barriers, and the educators' attitudes towards it. STEM education certainly has the potential to advance sustainability to a greater degree, but due to structural barriers, its effectiveness is heavily limited. These findings are aligned with international literature but also illustrate some specific challenges pertaining to the country.

6.1. Comparison with Global Practices

Based on data from Marginson et al. (2013) and Bybee (2013), Finland, Singapore, and the US have managed to incorporate STEM into the curriculum through inquiry-based methods and pedagogy, digital resources, and intensive teacher training. Singapore focuses on project-based learning in innovation-based economies and problem-based learning in Finland (Sahlberg, 2015). In Pakistan, many teachers lack the resources necessary to create a sustainable project-centered learning environment, particularly robotics, coding, and sustainability-focused resources.

6.2. Alignment with the Sustainable Development Goals (SDGs)

The results highlight STEM's possible contributions to various United Nations

Sustainable Development Goals. Teachers understood its contribution to fostering eco literacy (SDG 13 – Climate Action) and techniques for solving sustainability-related problems (SDG 4 – Quality Education). Moreover, STEM can equip learners for the participation in the green economy and other future-oriented professions (SDG 9 – Industry, Innovation, and Infrastructure). However, in Pakistan, the realization of these possibilities is constrained by low levels of institutional support and gaps in classroom implementation of the UN 2030 Agenda."

6.3. Gap in Policies

The policy discourse and execution diverge significantly owing to the existing disconnect. While the Single National Curriculum (SNC) and the Commission for the Higher Education (HEC) in Pakistan focus on advancing STEM education, teachers cite inflexible curricular structures, insufficient pedagogical preparation, restricted access to specialist resources, and the absence of appropriate STEM laboratories as fundamental career barriers. These obstructions serve as fundamental indicators of far-reaching structural issues and cycles of stagnation. If obstructions of this nature continue without redress, the discipline of STEM education will fall far short of its potential to serve Pakistan's sustainable development goals.

6.4. Implications for Education Reforms and Digital Transformation

The findings point toward several implications for reform:

1) Teacher Professional Development: Continuous professional learning opportunities, such as STEM-focused workshops, are essential for moving beyond rote learning toward inquiry-driven and technology-rich pedagogies.
2) Infrastructure and Digital Access: Investments in affordable laboratories, internet connectivity, and digital simulations are necessary

to reduce the urban–rural divide.

3) Curriculum Reform: STEM content must be integrated with sustainability themes, including climate change, renewable energy, and resource management.
4) Public–Private Partnerships: Collaboration with industries and universities can provide practical exposure, link classroom learning with labor market demands, and contextualize instruction for Pakistan's economic development.

When effectively implemented, these reforms could bridge the persistent policy–practice gap and position STEM education as a catalyst for Pakistan's digital transformation and sustainable development trajectory.

7. Conclusion

This research has also shown that STEM education may act as a pillar of advancement of sustainable development in Pakistan. The teachers pointed out the development of eco-literacy, development of problem-solving capabilities as well as the development of green capacity problem-solving development eco-capacity development and problem- solving development. Nevertheless, the results also pointed out critical missing elements such as, skilling the teachers and tailoring the curricula to better support the elements of sustainability. There are some well-resourced schools which have managed to integrate project-based learning into the curriculum. However, such practice is limited and unevenly distributed. To fully harness the STEM promise, rigid systemic changes are necessary. These changes incorporate deepening and broadening the sustainability prism of teacher capacity development, geo-sustainability, and sustainability in the disciplines in interdisciplinary teacher training as well as cross-cutting collaboration between the industry and the university.

Ultimately, the success of Pakistan's STEM education agenda hinges on

consistent institutional support, selective funding, and pedagogical novel ideas. Solving these systemic issues would allow Pakistan to use STEM education as a tool for national development, and international collaboration regarding advancement in technology and sustainability.

8. Recommendations

This research identifies several key areas where targeted initiatives can strengthen the impact of STEM education on sustainability in Pakistan.

Policy Integration: Case in point, funding needs to be strategically allocated to the lab construction in rural areas and public schools STEM infrastructure, with an emphasis on SDG 4 (quality education) and SDG 9 (industry, innovation and infrastructure) and SDG 13 (climate action) to construct well aligned national curricula on SDGs frameworks. Also, integration and uniformity at the provincial and administrative level across the country will be the goals of a national STEM policy to minimize fragmentation and compartmentalization in STEM education in provincial and administrative systems.

Teacher Training and Professional Development: Training should include interactive, technology-enhanced, problem based, and self-paced online learning. Instruction and curriculum need to be modernized, and frameworks developed to actively engage teachers with the tools to be sustainable leaders. Lifelong learning and adequate, continuous STEM instruction are essential, as are innovation and old mindsets in curriculum design to shift the focus to active and inquiry-based learning. Innovative STEM teaching in schools and across regions will be encouraged by exchange and mentoring programs.

School and Community Engagement: The role of schools and the surrounding communities is establishing STEM for sustainability. Experiential learning activities should assist students in the application of STEM knowledge to resolve local environmental and social issues. The integration of culturally

responsive and STEM learning modules that are locally accessible and economically helps to improve engagement and accessibility.

University-Level Reforms: university-level teacher education programs need to incorporate STEM inquiry training along with sustainability and digital pedagogy. The creation of research and innovation centers for pre-service teachers would improve STEM readiness and strengthen university-school collaboration. Such partnerships would help reduce the gap between theory and practice instruction in the classroom.

Cross-Sector Collaboration: Realistic STEM innovation centers collaboration between government, business, and education. Partnerships can give teachers and students access to valuable resources, knowledge, and practical experience. Corporate Social Responsibility (CSR) programs, aided by international partnerships, can bring global models and practices to the Pakistani context. Such partnerships bring STEM education to the forefront in order to fill the persistent gaps and provide a comprehensive and holistic vision for the sustainable development of the country.

References

ASER Pakistan. (2020). Annual Status of Education Report 2020. South Asian Forum for Education Development.

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. National Science Teachers Association Press.

Idrees, H., & Jabeen, N. (2021). STEM education in Pakistan: Opportunities, challenges, and policy implications. Journal of Education and Educational Development, 8(1), 13–29. https://doi.org/10.22555/joeed.v8i1.3575

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). STEM: Country comparisons. Australian Council of Learned Academies.

Rehmani, A. (2019). Teacher education in Pakistan: Analysis of planning issues

in preparing quality teachers. International Journal of Educational Development, 65, 125–135. https://doi.org/10.1016/j.ijedudev.2018.12.003

Tan, C. Y., Liew, Y. L., & Chua, J. S. (2019). STEM education in Singapore schools: A policy, curricular, and pedagogical overview. Asia-Pacific Science Education, 5(1), 1–20. https://doi.org/10.1186/s41029-019-0034-y

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018). The influence of teachers' attitudes and school context on STEM integration. Teaching and Teacher Education, 71, 190–205. https://doi.org/10.1016/j.tate.2017.12.014

UNESCO. (2016). Education for people and planet: Creating sustainable futures for all. UNESCO Publishing.

UNESCO. (2020). Education for sustainable development: A roadmap. UNESCO Publishing.

World Bank. (2019). Pakistan: Revitalizing higher education for sustainable growth. The World Bank.

Beier, M. E., Kim, M. H., Saterbak, A., Leautaud, V., Bishnoi, S., & Gilberto, J. M. (2019). The effect of authentic, inquiry based learning on attitudes and career aspirations in STEM. Journal of Research in Science Teaching, 56(1), 3–23. https://doi.org/10.1002/tea.21465

Biasutti, M., & Frate, S. (2017). A validity and reliability study of the attitudes toward sustainable development scale. Environmental Education Research, 23(2), 214–230. https://doi.org/10.1080/13504622.2016.1146660

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. National Science Teachers Association Press.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark. Educational Psychologist, 42(2), 99–107. https://doi.org/10.1080/00461520701263368

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? Contemporary Issues in Technology and Teacher Education, 9(1), 60–70.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). STEM: Country comparisons. Australian Council of Learned Academies.

Piaget, J. (1970). Science of education and the psychology of the child. Orion Press.

Rehmani, A. (2019). Teacher education in Pakistan: Analysis of planning issues in preparing quality teachers. International Journal of Educational Development, 65, 125–135. https://doi.org/10.1016/j.ijedudev.2018.12.003

UNESCO. (2016). Education for people and planet: Creating sustainable futures for all. UNESCO Publishing.

UNESCO. (2020). Education for sustainable development: A roadmap. UNESCO Publishing.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

Beier, M. E., Kim, M. H., Saterbak, A., Leautaud, V., Bishnoi, S., & Gilberto, J. M. (2019). The effect of authentic, inquiry-based learning on attitudes and career aspirations in STEM. Journal of Research in Science Teaching, 56(1), 3–23. https://doi.org/10.1002/tea.21465

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. National Science Teachers Association Press.

El-Deghaidy, H., Mansour, N., Alzaghibi, M., & Alhammad, K. (2017). Context of STEM integration in schools: Views from in-service science teachers. EURASIA Journal of Mathematics Science and Technology Education, 13(6), 2459–2484. https://doi.org/10.12973/eurasia.2017.01235a

HEC. (2021). National Research Program for Universities (NRPU). Higher

Education Commission Pakistan. https://www.hec.gov.pk

Hoodbhoy, P. (2020). Pakistan's Single National Curriculum: A step forward or backward? Dawn. https://www.dawn.com

Khalid, A., & Khan, S. (2019). STEM education in Pakistan: Opportunities and challenges. Bulletin of Education and Research, 41(2), 33–50.

Mahmood, K. (2021). Impact of digital divide on online education in Pakistan during COVID-19 pandemic. Education and Information Technologies, 26(6), 7243–7260. https://doi.org/10.1007/s10639-021-10512-9

Ministry of Science and Technology. (2019). STEM initiatives in Pakistan. Government of Pakistan. http://most.gov.pk

Niemi, H., Toom, A., & Kallioniemi, A. (2016). Miracle of education: The principles and practices of teaching and learning in Finnish schools. Springer.

Tan, J., & Leong, Y. H. (2014). Singapore's systemic approach to teaching and learning mathematics. ZDM, 46(6), 831–843. https://doi.org/10.1007/s11858-014-0615-0

U.S. Department of Education. (2016). STEM 2026: A vision for innovation in STEM education. https://www.ed.gov/stem

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Creswell, J. W., & Plano Clark, V. L. (2018). Designing and conducting mixed methods research (3rd ed.). SAGE Publications.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. American Journal of Theoretical and Applied Statistics, 5(1), 1–4. https://doi.org/10.11648/j.ajtas.20160501.11

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough?

An experiment with data saturation and variability. Field Methods, 18(1), 59–82. https://doi.org/10.1177/1525822X05279903

Khalid, A., & Khan, S. (2019). STEM education in Pakistan: Opportunities and challenges. Bulletin of Education and Research, 41(2), 33–50.