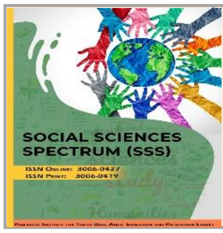

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The STEM Readiness Paradigm: Mapping Teacher Competencies and Innovation Pathways in Punjab's Public Schools

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Abstract

STEM education (Science, Technology, Engineering, and Mathematics) is a building block of world economic and educational advancement, which endows learners with analytical, problem-solving, and technological abilities essential for the 21st century. The public education system of Pakistan has too many hurdles to adopt quality STEM education through institutional mechanisms such as inadequate training for teachers, paucity of institutional backing, and poor access to advanced instructional tools. This research investigates the readiness of public school teachers in Lahore, Punjab, to teach STEM, using the creation of a STEM Teaching Readiness Matrix (STRM). A mixed-methods approach was used, combining 200 survey responses and qualitative interviews with 20 purposively selected teachers. The results show that the subject knowledge of teachers varies while their pedagogical confidence is low, especially when implementing interdisciplinary STEM ideas. Institutional support came out as the best predictor of effective STEM instruction, reflecting on the decisive significance of infrastructure, professional training, and administrative support. The study emphasizes the necessity for urgent policy interventions, the development of upgraded training programs, and resource deployment to facilitate bridging the divide between theoretical STEM instruction and experimental, practical training opportunities.

Keywords: STEM Education, Analytical, Teaching Readiness, Public School, Instruction and Experimental.

1. Introduction

Science education forms the basis for the development of a scientifically informed and empowered community that can confront complex issues. It promotes critical thinking, problem-solving, creativity, and ethics while providing the skills and information needed to be successful in a changing world (Alexandre et al., 2022). Science as a field is the study of nature and a systematic method of knowing (Bacovic et al., 2022). It is practical, inferential, innovative, hypothetical, and socially and culturally influenced to a great extent. Science is not just an aggregation of knowledge but also a dynamic and ever-changing process that keeps advancing through refinement and revision. Furthermore, science instills intellectual curiosity and love for knowledge (Abbas et al., 2024; Bacovic et al., 2022; Bibi et al., 2024).

Etymologically, the "S" in STEM (Science, Technology, Engineering, and Mathematics) signifies the investigation of the natural world, which is corpus of knowledge and an aggregate of facts that lead to understanding and discovery(Darmawansah et al., 2023; Hacıoğlu & Gülhan, 2021; Jamali et al., 2023). Science education leads students to explore, form hypotheses, make investigations, and interpret data with the aid of scientific principles in physics, chemistry, and biology (Card & Payne, 2021). The "T" for Technology deals with human innovation, natural resource adaptation, and the creation of tools and products to address societal demands (Rafiq, Iqbal & Afzal, 2024). Engineering, symbolized by the "E" in STEM, utilizes scientific principles based on rational reasoning to design and employ materials for the benefit of humanity. Lastly, Mathematics, the "M" in STEM, is the underpinning framework for science, technology, and engineering, allowing for the identification of patterns and reasoning. It is a cross-disciplinary subject that promotes higher-order thinking and problem-solving (Alexandre et al., 2022).

STEM education defenders identify its value in preparing students with necessary skills for the 21st century, sustaining educational quality, and enhancing STEM career pathways. Throughout society, people of various backgrounds make substantial contributions to scientific advancements, technology, engineering, and mathematics and affect both knowledge production and applied aspects (Bacovic et al., 2022; Bibi et al., 2024; Daraz et al., 2024). STEM education develops curiosity and interest in learning among students (Card & Payne, 2021).

In contrast to conventional learning, STEM is based on an interdisciplinary model that promotes problem-solving and active learning (Kayan-Fadlelmula et al., 2022). It motivates students by increasing their level of achievement and motivation throughout the teaching-learning process. The success of STEM learning relies on essential components in a curriculum, such as textbooks, instructional strategies, and student testing (Darmawansah et al., 2023; Hacıoğlu & Gülhan, 2021). These factors serve as catalysts in filling gaps in curriculum delivery, impacting students' knowledge gain and learning results (SLOs) directly. In order to harmonize STEM education with curriculum standards, instructional materials—like textbooks, instructor guides, teaching methodologies, and evaluation methods—are meticulously designed (Khadim, Rafiq & Afzal, 2023). Moreover, teacher training courses play a pivotal role in providing instructors with cutting-edge techniques for enhancing classroom instruction (Jamali et al., 2023).

Scientific progress is currently available to everybody at all stages. STEM education transforms students beyond ordinary learning styles and enables them to use the gained knowledge to their advantage in day-to-day activities (Kayan-Fadlelmula et al., 2022). It broadens their problem-solving capabilities as well as mathematical problem-solving capacities. Satisfying STEM education objectives involves active classroom involvement, as educational and cognitive development in students relies on their engagement and experience-based learning (Rafiq, Kamran

& Afzal, 2024). Effective teaching has a direct correlation with enhanced students' outcomes (Daraz et al., 2024).

The value of STEM education has received international attention as countries compete to prepare students with the skills needed for the contemporary, technology-based economy. The history of STEM education can be traced to the issue of whether students were ready for high-tech careers(Marushko et al., 2023; Muthatiyar & Ali, 2021; Newell & Ulrich, 2022). In 1983, the U.S. National Council for Educational Excellence (NCEE) recognized gaps in core areas of study, such as mathematics, science, and computer science, risking critical damage to national development. Governments around the world responded by making these subjects the central pillars of education, guaranteeing their inclusion in early childhood curricula. Seeing the importance of science education, most nations incorporated it as a mandatory subject in primary and elementary levels, even though it is considered a tough subject (Khan & Danish Sarfraz, 2024).

In 2001, the U.S. National Science Foundation (NSF) officially recognized the use of "STEM" as a reaction to concerns that the students were not being properly prepared for jobs in science, technology, engineering, and mathematics. This effort became more vigorous as international assessments, including the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA), showed steep gaps in students' scientific and mathematical abilities (Rakićević et al., 2022; Razali & Rahman, 2021; Sahito & Wassan, 2024). These results stimulated cross-national comparisons and prompted policymakers to reconsider education systems worldwide in order to enhance STEM learning achievements. With greater international consciousness of STEM education, its relevance has been more apparent than ever before, with governments, schools, and industries uniting to enhance STEM curricula and encourage innovation (Card & Payne, 2021; Daraz et al., 2024; Hacıoğlu & Gülhan, 2021; Jamali et al., 2023; Kayan-Fadlelmula et al., 2022).

STEM education is now seen as the driver of economic development, technological innovation, and workforce preparedness. Foreign nations are making policies and changes to incorporate STEM into their educational systems, stimulating problem-solving, critical thinking, and creativity among students (Rafiq, Zaki & Nawaz, 2025). Interdisciplinary learning, experiential learning, and relevance to real-world applications have become the defining feature of educating the next generation of scientists, engineers, and innovators (Darmawansah et al., 2023). As countries continue to make investments in STEM education, the world trend of scientific literacy and technological know-how is constructing the future of education and economic growth globally (Rafiq, Nawaz & Afzal, 2025). The advancement of STEM education at a fast pace can be seen in comprehensive research across the globe (Kayan-Fadlelmula et al., 2022). A quick Google search using terms such as "STEM," "STEM education," or "STEM education research" produces more than 4.5 billion results, which is a testament to the broad academic and policy concern in the area. Pakistan's education system in STEM is gradually evolving to meet the 21st century (Jamali et al., 2023).

Nonetheless, in spite of the considerable efforts exerted, the nation still lags behind in poor STEM awareness and literacy, especially at its K-12 and tertiary education levels. This deficiency places Pakistan on the lowest-ranked nations in the world in terms of capability in STEM, with high impediments to national economic advancement and international competitiveness (Khan et al., 2024). It is triggered by the quick pace of the revolution in technology witnessed by the world, with follow-on labor demands shifting away from labor alone toward technological and analytical skills (Rafiq, Kamran & Afzal, 2024). Whilst those nations who adopted STEM as their education mantra experienced considerable economic and technological progress, Pakistan trailed behind, not to mention burdened by such chronic ailments like outdated curricula, incompetent pedagogy, and student inadequacy with respect to exposure to practice (Khan & Danish Sarfraz, 2024).

The greatest obstacle to STEM education in Pakistan is the rote-learning system, which focuses more on memorization rather than conceptualization and problem-solving. The rote-learning system does not encourage creativity and critical thinking, both of which are essential for a strong foundation of STEM (Kayan-Fadlelmula et al., 2022; Khan & Danish Sarfraz, 2024; Lavi et al., 2024). The decline of science education is further exacerbated by the lack of trained teachers, since most teachers are not specifically trained to instruct STEM. Teacher training is still inadequate to prepare them with the appropriate pedagogical and technical competence, resulting in ineffective classroom teaching and delays in student learning and outcomes. Lacking effective instructors to teach STEM material, students find it hard to understand core principles, and hence, their overall academic performance decreases and interest in STEM professional development is lost (Lavi et al., 2024).

Apart from instruction techniques, there is also a critical shortage of properly equipped labs and technological inputs, especially in rural and low-income regions. Experimental learning and access to technology are important drivers of curiosity and problem-solving capacity in students, but most of Pakistan's schools are devoid of proper infrastructure (Hacıoğlu & Gülhan, 2021; Jamali et al., 2023). This discrepancy between theoretical knowledge and real-world application tends to make STEM subjects seem abstract and unrelated to actual issues, further demotivating students to enter the fields of science, technology, engineering, and mathematics. The current STEM curricula are also antiquated and lack interdisciplinary learning, contemporary advancements, and real-world uses. Therefore, students do not appreciate how STEM studies are connected to their future working lives, and their career opportunities and aspirations are curtailed in such fields (Card & Payne, 2021; Darmawansah et al., 2023; Khan & Danish Sarfraz, 2024; Lavi et al., 2024; Martinez Jr & Ellis, 2023).

Cognizant of these issues, the Government of Pakistan has promoted policies to enhance STEM education by establishing well-defined goals, stakeholder engagement, and curricula that focus on cognitive, social, and educational growth (Sansing-Helton et al., 2021). Guidelines for national curriculum have been designed with input from teachers, school officials, and policymakers to help provide a formalized strategy to STEM education. Nonetheless, despite the well-designed curriculum for general science on paper, poor implementation greatly slows the learning outcomes of the students (Bacovic et al., 2022). The gap between policy making and classroom implementation remains a significant hindrance, keeping the students from acquiring the analytical and problem-solving capabilities needed to flourish in STEM careers (Card & Payne, 2021). Additionally, weak coordination among the different stakeholders—such as government agencies, schools, industries, and parents—has further stalled development (Wan et al., 2021). There has to be coordination among these groups to deliver both academic content and practical exposure to the students, but that is not available in Pakistan at this level. This disjointed strategy does not equip the students with the proper skills to match the increasing demands of STEM jobs (Alexandre et al., 2022; Bibi et al., 2024; Hacıoğlu & Gülhan, 2021; Jamali et al., 2023; Khan et al., 2024; Lavi et al., 2024; Martinez Jr & Ellis, 2023; Marushko et al., 2023; Muthatiyar & Ali, 2021).

Despite these challenges, Pakistani students have a general disposition towards the learning of STEM subjects, particularly physics (Permanasari et al., 2021), chemistry (Sahito & Wassan, 2024), biology (Razali & Rahman, 2021), engineering (Sansing-Helton et al., 2021), and mathematics (Sulaeman et al., 2022). Technology, particularly, is considered a fascinating and worthwhile subject of study with far-reaching positive impacts on both learning and career opportunities. Learning conditions, however, do not completely enable the interest in so far as teachers' practices are traditional and fail to support critical thinking and problem-solving (Abbas et al., 2024; Bibi et al., 2024; Card & Payne, 2021). Too many teachers still use passive, lecture-style instruction instead of active, inquiry-based instruction that evokes student curiosity and interest. Without an education system that supports active learning and critical thinking, students cannot build the computational and reasoning skills needed to thrive in STEM careers (Vaidya, 2024). Moreover, there is no place given in any form or kind to incorporating the new technologies of artificial intelligence, robotics, and data science within the STEM teaching program, and that further contributes to the gulf between educational standards in Pakistan and the evolving global technology scenario (Darmawansah et al., 2023; Kayan-Fadlelmula et al., 2022; Khan et al., 2024; Mabsutsah et al., 2023; Martinez Jr & Ellis, 2023). Given the core position of STEM education in driving innovation, problem-solving, and technological progression, it is vital to study the preparedness of teachers who constitute the backbone of this framework. In Pakistan, especially in public schools, various impediments in the implementation of effective STEM education exist, such as insufficient preparation of teachers, outdated curriculum, and inaccessible resources (Vaidya, 2024; Villalta-Cerdas et al., 2022). A systematic approach must be followed in order to measure and improve STEM teaching preparedness (Darmawansah et al., 2023; Mabsutsah et al., 2023; Martinez Jr & Ellis, 2023).

This research assessed the preparedness of public school teachers in Lahore, Punjab, to teach STEM subjects effectively by measuring their competencies, subject matter knowledge, and pedagogical self-efficacy. It aims to investigate how effectively teachers incorporate science, technology, engineering, and mathematics into their teaching and whether they have the skills required to apply interdisciplinary and student-centered approaches to teaching. Furthermore, the study revealed institutional and resource-based obstacles that influence STEM education, such as access to professional development, laboratory space, computer equipment, and administrative assistance. Through the exploration of these determinants, the study aims to shed light on the challenges encountered by teachers and the systemic shortcomings that must be bridged in order to improve STEM education in public schools.

2. Methodology

2.1. Research Design

This research utilizes the mixed-methods strategy, incorporating both quantitative and qualitative data collection methods to determine STEM teaching readiness among Punjab's public school teachers. A survey and semi-structured interviews were employed to capture information on teachers' competencies, challenges, and institutional support in STEM. The research took place over the course of six months in Lahore, Punjab, selected for its heterogeneity in terms of education, ease of access to policymakers, and inclusion of both urban and semi-urban public schools. Lahore comprises about 1,219 public schools.

The present study was carried out in Lahore, Punjab, a district with an estimated population of about 13.979 million as of the 2023 census, of which 52% were males and 48% females lahore.punjab.gov.pk .The overall literacy rate of 73% in Lahore was recorded, which indicates a comparatively high level of education against other areas lahore.punjab.gov.pk The administrative area of Lahore is comprised of Lahore City Tehsil and Lahore Cantt Tehsil. The literacy rate of the urban population is 77.08%, that of males being 79.19% and females being 74.75% pbs.gov.pk. This research considered only public sector primary schools in Lahore, where the Government of Punjab has recently launched STEM education programs in 43 districts lahore.punjab.gov.pk.

Ethical issues were carefully respected. The leaders of the institutions and instructors were assured that data gathered would only be used for research purposes. Authors ensured strict adherence to ethical guidelines, such as informed consent, anonymity, confidentiality, and no physical or psychological harm assurance to participants, highlighting voluntary participation.

2.2. Participants and Data Collection

This research included 200 public school teachers from Lahore, who were chosen using stratified random sampling to provide coverage across various school types, geographic locations, and levels of experience. The process of data collection was conducted over two phases: quantitative surveys and qualitative interviews.

1. Surveys (Quantitative Data Collection)

Surveys: Standardized questionnaires were used to assess different dimensions of STEM teaching preparedness. Pedagogical Knowledge was measured to check whether teachers can incorporate inter-disciplinary knowledge and apply contemporary instructional techniques. Science, Technology, Engineering, and Mathematics (STEM) Knowledge was assessed to identify whether teachers have the required subject matter knowledge for effective teaching. Institutional Support was tested to check for the presence of school infrastructure, administrative support, and teaching materials. Finally, 21st-Century Skills were measured to test teachers' capability to develop problem-solving, innovation, and critical thinking skills among students—capabilities that are pertinent in today's fast-changing world of technology.

2. Interviews (Qualitative Data Collection)

Recent reports indicate a significant shortage of teachers in government schools across Punjab, with estimates suggesting a deficit of over 100,000 educators. tribune.com.pk This shortage is particularly pronounced in subjects such as science and mathematics, affecting both urban and rural areas. dawn.com In Lahore, this scarcity has led to challenges in effectively implementing STEM education programs. Piloting revealed challenges such as an absence of science teaching staff and facilities. Thus, convenience sampling was used to recruit the 20 interviewees who were to be interviewed concerning STEM implementation. They were selected in consideration of their science teaching experience and recruitment as Elementary School Educators (ESE) with a Science and Mathematics background

2.3. Data Analysis

Various statistical and qualitative analysis methods were utilized to explore the data that was gathered. Descriptive statistics were utilized in analyzing responses from surveys, determining mean scores, standard deviations, and agreement percentages in terms of teachers' competencies, confidence, and support from institutions. Correlation analysis was utilized in identifying relationships between support from institutions, pedagogical knowledge, and effectiveness of teaching STEM, emphasizing the critical factors affecting teacher readiness. Regression analysis was carried out to determine the most significant predictors of teaching effectiveness, with consideration to the institutional support and STEM integration roles in developing 21st-century skills. Thematic analysis was further carried out on the interview data, determining the thematic patterns of instructional challenges, teacher training requirements, and provision of STEM resources. These combined methods provided an exhaustive assessment of STEM teaching readiness and its determinants.

3. Results

3.1. Participants' Demographics

The demographic profile showed that the survey had an even distribution of male and female teachers, with 50% males and 50% females. The majority of the teachers were from the younger age groups, with 41% aged 20-30 years and 29% aged 31-40 years, and merely 20% were from the 41-50 years' age group with 9.5% of them being older than 50 years. This distribution indicates that a high percentage of the teaching population is quite young, with fewer experienced teachers to act as mentors and in leadership positions. The data on teaching experience also supported this pattern, as 55.5% of teachers had 1-5 years of experience, and 37.5% had 6-10 years, while only 12% had over 10 years of teaching experience. This suggests a possible gap in seasoned leadership in the STEM education field, which might affect the effective execution of new teaching methods. In terms of academic credentials, a significant percentage of teachers possessed higher degrees, with 38.5% having a Master's degree, 30% an MS/M.Phil, and 11.5% a PhD. Nonetheless, 20% of the respondents possessed only a graduate degree, which underscores the necessity for ongoing professional development to guarantee that all instructors possess the knowledge and skills required for teaching STEM. The qualitative findings from interviews also revealed a number of structural issues, such as a lack of STEM-specialized instructors, weak institution support, and poor access to contemporary teaching materials. The shortage of science and math teachers came as a major hindrance, in significant way impacting the implementation of STEM programs in Punjab's public schools.

Table 1: *Participants' Demographics*

Category	Group	Frequency	Percent
Gender	Male	100	50.0%
	Female	100	50.0%
	Total	**200**	**100.0%**
Age	20-30 years	83	41.0%
	31-40 years	58	29.0%
	41-50 years	40	20.0%
	50 above	19	9.5%
	Total	**200**	**100.0%**
Experience	1-5 years	101	55.5%
	6-10 years	75	37.5%
	11-15 years	11	5.5%
	16-20 years	13	6.5%
	Total	**200**	**100.0%**
Qualification	Graduate	40	20.0%
	Masters	77	38.5%
	MS/M.Phil	60	30.0%
	PhD	23	11.5%
	Total	**200**	**100.0%**

3.2. Survey Analysis

1. Teachers' STEM Knowledge & Confidence

A critical determinant of STEM readiness is measuring teachers' subject matter knowledge and confidence in using STEM concepts in their classrooms. The survey findings show that most teachers do not feel confident in their capacity to effectively teach STEM subjects, especially in the use of student-centered pedagogy, real-world contexts, and interdisciplinary connections.

The results indicate that just 33% of teachers are confident in pedagogical content knowledge for STEM, implying that most lack the ability to implement student-centered teaching strategies. The pedagogical confidence gap could impede active learning strategies, restricting students' participation in inquiry-based and problem-solving activities crucial for STEM learning.

With regard to subject-specific confidence, mathematics proved to be the strongest subject area, with 38% of teachers indicating familiarity with applying real-world math in their teaching. Yet, while this relative strength is evident, numerous teachers have difficulty incorporating mathematics with other STEM fields, something essential for teaching interdisciplinary problem-solving skills to students.

Table 2: *Teachers' STEM Knowledge Response Trends*

STEM Category	Teacher Response Trends
Pedagogical Knowledge	Only 33% of teachers feel confident in applying student-centered teaching methods in STEM.
Science (SCI)	Low confidence (28%) in applying real-world science examples and conducting experiments.
Technology (TEC)	35% report difficulties using digital tools in STEM instruction.
Engineering (ENGI)	Only 22% incorporate engineering principles into lessons.
Mathematics (MATH)	38% use real-life math applications, but integration with other STEM subjects remains weak.

Conversely, engineering and technology content were the areas of greatest weakness, with only 22% of educators teaching engineering principles in their classrooms and 35% having difficulty with digital tools for STEM teaching. The lack of confidence in engineering education reflects a critical gap in training and resources, as engineering is a fundamental part of STEM that necessitates hands-on, design-based learning methods. In the same vein, technology integration is still a problem, perhaps for lack of access to digital instructional tools and inadequate preparation in technology-supported learning strategies.

Moreover, science teaching confidence is quite low, with only 28% of teachers being confident in using real-world science examples and experimenting. As science education is inquiry-based, this lack of confidence indicates that most teachers might be using textbook-based, theoretical instruction instead of hands-on, experiment-based instruction. This deficit could be because of limited exposure to laboratory materials, no effective training on inquiry-based methods, or excessive focus on rote learning from the existing education system.

2. STEM Teaching Readiness: Applying Knowledge in Classrooms

STEM teaching readiness means how well teachers can implement their knowledge within the classroom to bring about relevant learning opportunities for students. The teacher might possess subject matter knowledge, but it is essential that they can incorporate STEM ideas, utilize strong teaching methods, and work on enhancing students' problem-solving skills to help students achieve high-quality STEM education. Survey findings show that public school teachers in Lahore experience significant difficulties in providing STEM education, especially in integration of STEM, pedagogical knowledge, and 21st-century skill acquisition.

The results indicate that merely 29.81% of teachers are confident in incorporating STEM subjects into the curriculum. The low figure indicates that most teachers have difficulty with interlinking science, technology, engineering, and mathematics in an integrated manner. STEM education is interdisciplinary, and teachers must assist students in applying knowledge from one subject to another instead of studying them as distinct subjects. Yet, the insufficient confidence in integrating STEM indicates that the majority of teachers continue to teach these subjects separately, a move that can hinder students from gaining problem-solving and analytical mind skills required in actual STEM fields.

Table 3: *STEM Teaching Readiness Scores*

Category	Mean	Std Dev	% Agreement
Pedagogical Knowledge (PK)	3.04	1.26	33.21%
STEM Integration Knowledge	2.84	1.30	29.81%
Institutional Support	3.11	1.90	36.13%
21st-Century Skills (T1stCSK)	2.17	0.83	6.42%

Likewise, pedagogical knowledge (PK) scored poorly, with a mere 33.21% of teachers expressing confidence in their capacity to teach STEM effectively. Pedagogical knowledge is crucial for creating interesting, student-focused learning experiences that transcend the old rote learning approach. The low score in this area indicates that most teachers are not exposed to contemporary teaching methods, including inquiry-based learning, project-based learning, and collaborative problem-solving methodologies. Consequently, most of the STEM courses can be textbook-based, devoid of experiments and practical applications, which are so important in terms of engaging the students and deep learning.

The most alarming discovery in this area is the very low percentage of score in the development of 21st-century skills, as only 6.42% of teachers respond that they are able to effectively develop students' critical thinking, creativity, and innovation skills. In the rapidly changing world of today, STEM education is not merely about learning content but also about developing higher-order thinking capabilities. That over 90% of educators are not confident in developing such skills indicates an enormous shortfall in how STEM is being taught within public schools. Without active learning methods, problem-solving tasks, and real-world projects, students might not be well enough prepared for future STEM-related careers or innovation-based industries.

3. Institutional Support & Resource Availability

Even if teachers have STEM subject matter expertise and pedagogical training, their potential to provide effective STEM instruction is significantly determined by institutional support and access to resources. STEM education is experimental learning, experimentation, and computer-assisted instruction, all of which require adequate infrastructure, financing, and administrative backing. The results of the survey mirror critical deficiencies in institutional support, with substantial numbers of teachers reporting limited access to key STEM resources, limited professional development opportunities, and a lack of administrative support.

The most concerning find is that just 22.5% of teacher’s report that they have access to adequate lab equipment and computer tools. That leaves a massive majority of teachers without the resources needed to perform experimental work, simulate learning practice, or integrate technology into teaching. Without the availability of proper laboratory equipment and computer resources, STEM education is theoretical and not practical, which has a tendency to reduce students' interest and hinder problem-solving and analytical skills acquisition.

Table 4: *Institutional Support Scores*

Institutional Factor	Mean Score	% Agreement
Access to lab equipment & digital tools	2.71	22.5%
School provides STEM teaching support	3.11	36.13%
Opportunities for professional development	2.92	30.8%
Administrative encouragement for STEM	3.25	40.5%

Moreover, a mere 36.13% of teachers believe that their school offers adequate support for STEM teaching, indicating that most teachers lack institutional support to integrate STEM education. Although 40.5% of teachers report some administrative support for STEM education, the reported support for classroom implementation is much lower. This gap indicates that although school administration might acknowledge the significance of STEM, tangible actions like equipment funding, curriculum adjustments, and formal teacher support are still lacking.

Another key area is the inadequacy of professional development training, with 30.8% of the teachers reporting to have access to relevant STEM training. Ongoing professional development is key to maintaining teachers' exposure to new technologies, contemporary pedagogy, and inter-disciplinary methods in STEM. The low figure reflects that most of the teachers do not get the requisite training to upgrade their pedagogy, thereby further reducing their capacity to adopt innovative STEM practices in class.

4. Correlation Analysis: Relationships Between Key Factors

Knowledge of the interconnection between various facets of readiness in STEM is essential to recognize the most critical factors for successful STEM instruction. A correlation analysis was done to establish how pedagogy knowledge, knowledge of integrating STEM, and institutional support affect 21st-century skills development—one of the markers for teacher effectiveness to develop problem-solving, creativity, and innovation among students.

It is found that institutional support ($r = 0.477$) positively correlates most with 21st-century skill development. This indicates that those teachers who have better institutional support such as lab facilities, digital tools, administrative support, and professional training are much more effective in making students ready for current STEM challenges. This finding emphasizes the role of availability of resources and school leadership in the formulation of quality STEM education.

Pedagogical content knowledge ($r = 0.386$) and STEM integration content knowledge ($r = 0.371$) similarly show moderate positive correlations with 21st-century skill development. This implies that educators with greater pedagogical knowledge and capacity to integrate the STEM subjects are better placed to motivate students in higher-order thinking and problem-solving in everyday situations. These, however, are weaker correlations compared to administrative support, implying that even highly trained educators are unable to deliver effective STEM education in the absence of proper infrastructure and administrative support.

Table 5: *Correlation Between Variables*

Variable	Correlation with 21st-Century Skills	Interpretation
Pedagogical Knowledge (PK)	0.386 (moderate)	Teachers with stronger PK develop better student engagement.
STEM Integration (SCI, TEC, ENGI, MATH)	0.371 (moderate)	Better STEM integration enhances student engagement.
Institutional Support (INST)	0.477 (strongest effect)	Higher school support results in stronger teacher effectiveness.

5. Regression Analysis: Identifying Key Predictors of STEM Readiness

To determine the most influential drivers of STEM instruction effectiveness, regression analysis was conducted to examine the effect of STEM subject matter knowledge, technology knowledge, mathematical knowledge, and institutional support on teachers' ability to impart 21st-century skills to students. The results provide important insights into what aspects are most contributing to teacher readiness and which are potentially undermining effective STEM instruction.

The findings indicate that institutional support ($\beta = 0.076$, $p = 0.002$) is the strongest predictor of STEM readiness. This implies that teachers with more institutional support—i.e., professional development opportunities, resources to teach with, and administrative assistance—are significantly better at adopting STEM education. This finding resonates with prior evidence from the correlation analysis and again highlights the school's significant role in facilitating effective STEM instruction. Without adequate institutional support, even highly knowledgeable teachers may struggle to create engaging and effective STEM learning experiences.

Table 6: *Regression Analysis for 21st-Century Skills*

Predictor	β Coefficient	p-value	Significance
STEM Subject Knowledge (SCI2)	-0.099	0.000	Negative Impact
Technology Knowledge (TEC2)	0.056	0.032	*Significant*
Mathematics Knowledge (MATH2)	0.060	0.031	*Significant*
Institutional Support (INST4)	0.076	0.002	Highly Significant

Surprisingly, the findings indicate that science subject knowledge (SCI2) negatively affects teaching effectiveness ($\beta = -0.099$, $p = 0.000$). This unexpected result indicates that having STEM subject knowledge does not necessarily mean effective teaching. Perhaps the reason is that science teaching in Lahore's public schools is still very theoretical and lacks hands-on, practical applications. If instructors are only trained in memorization of content and not applied scientific thinking, their capacity to involve students in authentic STEM problem-solving can be undermined. This result emphasizes the necessity to reshape STEM training programs to emphasize not just subject matter knowledge but also how to effectively teach STEM through active learning strategies.

Conversely, technology knowledge (TEC2) and mathematics knowledge (MATH2) have positive and statistically significant impacts on teaching STEM ($\beta = 0.056$, $p = 0.032$ and $\beta = 0.060$, $p = 0.031$, respectively). This indicates that teachers who feel more at ease incorporating technology-driven learning tools and practical mathematical uses are more effective in developing 21stcentury skills among students. Yet, the comparatively low beta values suggest that although technology and mathematics play a role in successful STEM teaching, they are not enough by themselves. Their effect is probably enhanced when they are coupled with robust pedagogical practices and institutional backing.

To confirm the validity of the regression model, Variance Inflation Factor (VIF) values were calculated to check for multi-collinearity—a condition where independent variables are highly correlated, which can distort regression outcomes. A VIF value above 5 indicates high multi-collinearity, potentially undermining the model's reliability.

The results indicate that all VIF values are below 5, thus confirming that multi-collinearity is not present in this model. The highest VIF value (INST3 = 2.64) is also far below the acceptable level, showing that the variables are independent enough to provide reliable information on the STEM readiness of the teachers.

Table 7: *Collinearity Statistics (Variance Inflation Factor - VIF)*

Variable	VIF Value	Interpretation
PK1 - PK7 (Pedagogical Knowledge)	1.19 - 1.90	No multi-collinearity issue
SCI1 - SCI2 (Science Knowledge)	1.22 - 1.93	No multi-collinearity issue
TEC1 - TEC2 (Technology Knowledge)	1.69 - 2.07	No multi-collinearity issue
ENGI1 - ENGI2 (Engineering Knowledge)	1.41 - 2.11	No multi-collinearity issue
MATH1 - MATH2 (Mathematics Knowledge)	1.67 - 2.11	No multi-collinearity issue
INST1 - INST4 (Institutional Support)	1.18 - 2.64	Slight multi-collinearity in INST3, but within acceptable limits

3.3. Interview Analysis

The problems with the implementation of STEM education by public school teachers in Lahore are more than personal abilities; they lie institutionally, arising from a failure to train teachers effectively and paltry resources. Teachers interviewed highlighted serious impediments to teaching STEM, which were mainly caused by inadequate infrastructure, outdated training programs, low student interest, and inadequate administrative support. Even with such obstacles, other teachers have created creative solutions to improve STEM education, but their effects are contained without institutional reforms and budget allocation.

1. Lack of STEM Resources: Struggles with Insufficient Infrastructure

Among the biggest issues raised by teachers was the absence of basic STEM materials, which severely hinders their capacity to provide quality education. Science labs, computer hardware, and practical training equipment are lacking in most schools, compelling teachers to resort to theoretical teaching instead of practical learning.

A teacher of chemistry vented her frustration: *"We are expected to teach practical science, but we don't even have a functioning lab. We try to conduct experiments in a regular classroom, but it's not the same. The students don't get to engage with the materials properly, which affects their understanding."*

This was expressed by another teacher, who highlighted the issues of implementing technology in STEM lessons, adding, *"In the modern world, STEM education should be technology-driven, but* *our schools don't have projectors or even reliable internet. If I want to show students a simulation, I have to use my personal laptop and mobile data."*

The absence of technology tools also undermines students' capacity to visualize intricate STEM concepts, rendering learning abstract and detached from practical applications. Mathematics instructors also pointed out the constraints of conventional classroom environments, where interactive tools such as digital whiteboards or graphing software are not available.

One such teacher explained, *"Math is best taught with visual models, but our classrooms are just blackboards and chalk. If we had digital whiteboards or even projectors, I could demonstrate real-world applications better."*

2. Need for Teacher Training

Aside from resource constraints, teachers also complained of critical gaps in training programs that focus on theory instead of classroom application. Teachers generally reported being unable to implement STEM methods even after taking professional development courses.

A physics teacher shared her experience, saying, *"I attended a STEM workshop last year, but it was just a lecture on why STEM is important. There were no real demonstrations on how to teach STEM subjects using modern methods. When I went back to my classroom, I didn't feel any more prepared than before."*

This was echoed by another teacher, who denounced the old way of training, claiming, *"We were given books and PowerPoint slides about STEM methodologies, but there was no hands-on training. I need to see and practice new teaching methods, not just read about them."*

Another persistent theme was the requirement for ongoing professional development. One recently hired teacher described, *"STEM education is constantly evolving, with new technologies, new approaches, and new challenges. But once we finish our initial teacher training, we rarely get refresher courses. How can we improve if we are not given opportunities to update our skills?"*

3. Student Engagement Challenges

Teachers also voiced worries regarding low student interest, especially in STEM classes involving abstract thinking and problem-solving. Several cited that students find it difficult to be interested in lessons without practical applications or hands-on components.

A secondary school science teacher explained, *"STEM topics can be very abstract. Without real-world examples or practical experiments, students lose interest. When they can't visualize a concept, they struggle to understand it."*

Some teachers attempted to use group activities and authentic issues in an attempt to increase engagement, but they were constricted by limited resources.

A mathematics teacher shared, *"Whenever I can, I use group activities and problem-solving challenges. These activities get students excited about learning, but without proper materials, it's hard to make lessons truly interactive."*

A technology teacher further highlighted the **limitations of traditional assessment methods**, saying, *"We assess students through written tests, but STEM subjects should be evaluated differently. Students should be designing, building, and experimenting. When assessment is just multiple-choice questions and written answers, students don't see the practical value of what they're learning."*

4. Administrative Support Issues

Most of the teachers also complained about poor administrative support, indicating that although STEM is encouraged verbally, little policy initiative or funding is made available to enable its implementation.

A high school teacher expressed frustration over budget constraints, stating, *"Our principal always talks about how important STEM education is, but when we request funding for lab materials or training sessions, we are told there's no budget. If STEM is so important, why aren't resources being allocated to support it?"*

Others pointed out the **lack of long-term strategic planning**, with a middle school teacher noting, *"STEM education needs more than just enthusiasm from individual teachers. It requires school-wide strategies, funding, and curriculum adjustments. Right now, we are just expected to 'make it work' without real institutional backing."*

5. Effective Teaching Strategies

In spite of all the challenges, there are some teachers who have come up with innovative methods to keep students interested and make learning STEM more relevant.

A biology teacher shared her approach, saying, *"I try to use real-life examples so students can relate science concepts to their daily lives. For example, when teaching about photosynthesis, I ask them to observe how plants grow differently in sunlight versus shade. Simple activities like this make a big difference."*

Similarly, a mathematics teacher incorporates **storytelling and relatable examples** to improve student engagement: *"Instead of just solving equations, I create real-world problems that students can relate to. If I'm teaching percentages, I'll use examples from sports scores or shopping discounts. It helps students see why math matters."*

A technology teacher, despite the lack of school-provided digital tools, shared an **alternative strategy**: *"Since we don't have projectors, I sometimes ask students to research a topic on their mobile phones at home and present it to the class. It's not ideal, but it makes lessons more interactive and keeps students engaged."*

3.4. Alignment between Qualitative and Quantitative Results

The qualitative interview results enhance the quantitative survey data (Table 6), supporting primary challenges in STEM education. Teachers' experiences offer more depth to statistical trends, underscoring deficits in institutional resources, resource accessibility, and confidence in pedagogy. Overdependence on archaic teaching techniques and absence of hands-on tools further elucidate the challenges in promoting student interest and 21st-century competencies. Furthermore, the function of technology and mathematics in increasing STEM readiness is reinforced by teachers who highlight the value of real-world applications and computer tools. Such findings lay stress on the requirement for focused interventions, such as enhanced funding, hands-on teacher training, and a change towards interactive, student-engaged learning methods.

Table 8: *Alignment between Qualitative and Quantitative Results*

Quantitative Findings	Qualitative Explanation from Interviews
Institutional support is the strongest predictor of STEM readiness (β = 0.076, p = 0.002).	Teachers report lack of funding, STEM resources, and weak administrative support.
Only 22.5% of teachers have access to lab equipment & digital tools.	Teachers say schools lack proper labs and technology, forcing them to rely on theoretical instruction.
Only 33.21% of teachers feel confident in their pedagogical knowledge.	Teachers say training is too theoretical and lacks practical application.
Science knowledge negatively impacts STEM teaching effectiveness (β = -0.099, p = 0.000).	Teachers rely on outdated, theory-heavy teaching methods with little hands-on engagement.
Only 6.42% of teachers feel they successfully develop 21st-century skills.	Teachers struggle to keep students engaged due to lack of hands-on learning tools.
Technology & mathematics knowledge have positive effects on STEM readiness.	Teachers who use real-life examples & digital tools see better engagement.

These results highlight the necessity of policy changes, more funds for STEM resources, experiential teacher training, and a greater emphasis on interactive, student-centered instructional methods. These gaps must be addressed to enhance STEM education in the public schools of Lahore.

Discussion

The effective application of STEM education is determined by various factors, such as teachers' competencies, classroom settings, institutional support, and education policies. The results of this study identify major impediments to successful STEM instruction, consistent with existing research that focuses on the difficulties teachers encounter in providing STEM education. Like the research by (Permanasari et al., 2021), this study verifies the existence of a gap between teaching beliefs and STEM learning goals, further supporting the necessity for greater alignment between pedagogy and curriculum goals.

One of the significant issues identified is the weak pedagogical knowledge of the teachers, directly affecting the transfer of STEM concepts. The conclusion of this research supports the outcome of (Razali & Rahman, 2021), which identifies the lack of pedagogical knowledge among teachers to hinder the ability of students to comprehend STEM concepts. Conversely, instructors who undergo more stringent pedagogical training can greatly enhance students' understanding and long-term retention of STEM principles, as was demonstrated in studies by (Sahito & Wassan, 2024). Findings underscore the urgent need to reexamine teacher training programs so that they are infused with modern, student-centered STEM methods.

Additionally, the study advocates for curriculum reforms in an effort to improve the quality of STEM education. Research conducted by (Shidiq & Nasrudin, 2021)) reveals that outdated science and STEM curricula limit student engagement and fail to develop higher-order thinking skills. This is evidenced by the current study findings that highlight the need to revise pedagogical practices and ensure practical learning in STEM courses.

The study also suggests poor funding and resource utilization as major challenges to STEM education, in support of previous work by (Villalta-Cerdas et al., 2022). Without enough investment, schools do not have the highly equipped labs, computer hardware, and current instructional materials to aid the applied use of STEM concepts. Besides, traditional pedagogical practices remain a recurring hindrance, as noted by (Walton et al., 2024), to induce disconnection and ignorance among students towards STEM fields of study.

In addition, classroom settings play a significant role in STEM learning (Walton et al., 2024; Wan et al., 2021). A study conducted by (Wu et al., 2022) points out that class size reduction increases academic performance, especially for disadvantaged students. The study supports the need for designing favorable learning spaces, especially laboratory settings, where experimentation through hands-on learning is essential for STEM education. But the research shows that most schools do not have the required infrastructure, teaching materials, and teacher support systems, which present serious challenges to effective STEM teaching.

To address such issues, the policymakers and authorities in schools have to prioritize STEM education by allocating funds to acquire facilities, appointing sufficient qualified teachers, and supplying up-to-date teaching aids. In some places where the availability of teaching aids is nonexistent, the educators must be qualified to improvise and utilize non-traditional teaching methods as suggested by (Xu & Ouyang, 2022). Consolidating teacher training programs, improving funding mechanisms, and encouraging innovative pedagogical approaches are the most important steps towards reinforcing STEM education and equipping students for future scientific and technological revolution.

Conclusion

The research underscores major gaps in readiness of STEM teaching in Lahore's public schools, most importantly due to inadequate institutional support, archaic pedagogic training, and poor access to cutting-edge teaching materials. The quantitative data shows that institutional support is key in boosting teachers' effectiveness, while qualitative data underscores the practical challenges faced by teachers to teach STEM material. The absence of experiential learning opportunities, poor professional development, and limited resources undermine effective STEM education, ultimately affecting students' learning and engagement. To overcome these challenges, policymakers need to focus on improving infrastructure, investing in ongoing STEM-themed teacher training, and promoting greater alignment between theoretical teaching and practical applications. Enhancing administrative assistance and promoting interdisciplinary learning methods are fundamental towards enhancing STEM education in the public schools of Pakistan to the extent that students are properly prepared with the skills they need to succeed in a rapidly technology-based global world.

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