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Urban-Rural STEM Education's Influence on Creativity in Public and Private Middle Schools of Pakistan

Kamlish
National University of Sciences and Technology

Khushal Das
University of Calabria

Abstract: This study examines the influence of STEM (Science, Technology, Engineering, and Mathematics) education on nurturing creativity and innovation among middle school students in Pakistan. A total of 164 students participating in diverse STEM programs nationwide provided data through a comprehensive questionnaire addressing demographics, perceptions, STEM engagement, and creativity skills. The findings highlight a gap in the current curriculum's ability to develop essential skills while also underscoring the positive impact of STEM education on nurturing creativity, critical thinking, and analytical capabilities. There were differences in the levels between urban and rural settings and public and private schools regarding the intensity of engagement and perceived benefits of urban and private institutions. Therefore, this study will inform educators, policymakers, and curriculum developers about the necessity of integrating in-school STEM programs into the Pakistani educational system. Future research may employ longitudinal and qualitative approaches to better understand students' experiences and the sustained impact of STEM education.

Keywords: STEM education, Middle school students, Creativity, Educational policy, STEM education in Pakistan, Curriculum development

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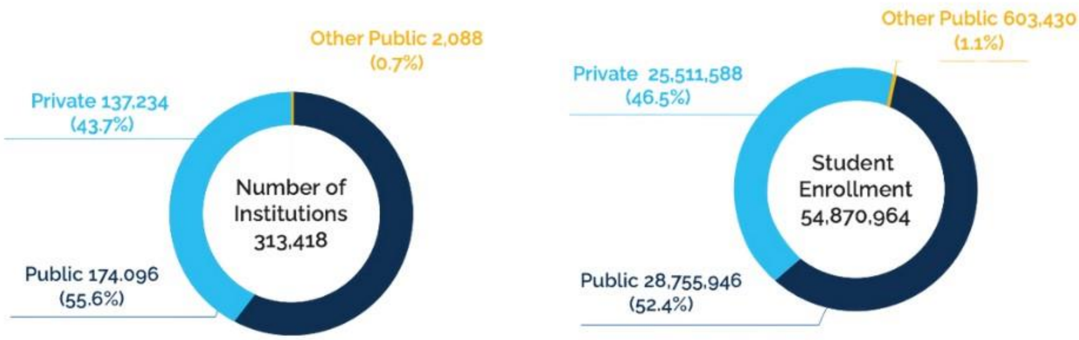
Urban-Rural STEM Education's Influence on Creativity in Public and Private Middle Schools of Pakistan

STEM (Science, Technology, Engineering, and Mathematics) education has emerged as a key component in preparing students to handle the complexities and opportunities brought about by the 21st century (Tytler, 2020). The emphasis that STEM education has received in most countries is informed by the increasing demand for a competent workforce in scientific inquiry, technological innovation, engineering design, and mathematical problem-solving (Perry, 2022). This thrust, particularly in Pakistan, where human resource development in the field of STEM has become increasingly dire, remains highly relevant for economic modernization and international competitiveness (Mohib, 2023). Aslam et al. (2022) have resonated with the notion that improving STEM education in Pakistan directly impacts the national aspiration of achieving sustainable economic growth coupled with technological development. As indicated by the report on education statistics from the Pakistan Institute of Education (Team, 2024), a total of 313,418 educational institutions are in Pakistan. Of those, 43.8% represent private schools, and 52.2% are public. Interestingly, about 46.5% of the students are enrolled in private schools as opposed to 53.5% in public ones, shown in Figure 1.

Figure 1

Overview of Pakistan's Education System by Institution Type (Team, 2024)



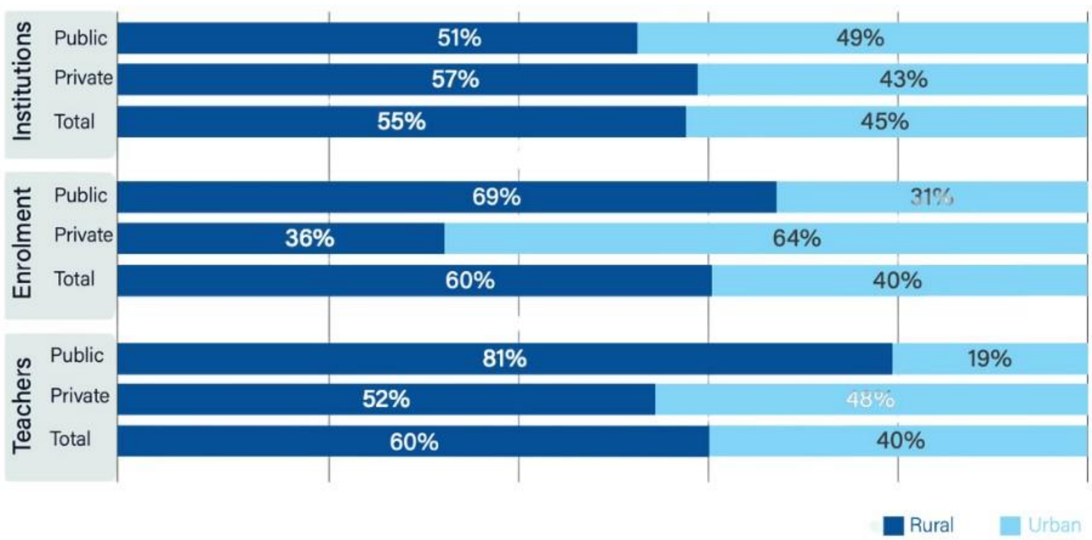
Recent studies have highlighted the role of computational thinking in enhancing student performance. Bounou et al. (2023) found a positive relationship between computational thinking ability and high school students' performance in languages and STEM. This highlights the role of integrating computational skills in STEM curricula to enhance academic performance. Beyond curriculum reform, parental influence plays a critical role in shaping students' attitudes towards STEM. Küçükaydın and Ayaz (2025) indicate that parents' knowledge regarding STEM is directly related to their children's career choices and attitudes. This suggests that a positive home climate can be as influential as augmenting in-school resources in promoting engagement in STEM.

Furthermore, recent studies point to a positive role for a curriculum integrating STEM in fostering design thinking attitudes. Thomason and Hsu (2024) demonstrated that integrating STEM disciplines can enhance middle school students' capacity for creatively solving problems and developing critical design thinking skills, a prerequisite for innovative learning. This is consistent with the overall goal to prepare students for 21st-century challenges.

Middle school is a formative stage in students' academic life for developing their interest in improving their critical thinking, creativity, and problem-solving skills (Israel Fishelson &

Hershkovitz, 2022). These formative years can shape their future academic and professional trajectory and motivate them to pursue a career in fields related to STEM (Tai et al., 2006). However, Pakistan's education system for STEM is marked with disparities in access and quality (Nazli & Noman, 2023). There is a wide contrast between public and private schools and urban and rural areas in resources, infrastructure, and pedagogy. This difference is further evidenced by a recent study by Hali et al. (2021), which showed that private schools in Pakistan tend to have more visible and robust STEM education programs compared to their public counterparts, highlighting the need for targeted interventions to improve STEM education access and quality in public schools (Team, 2024). The Report (Team, 2024) also shows that rural areas have a higher percentage of public institutions (51%) compared to urban areas (49%), while urban areas have a greater share of private institutions. For student enrollment, 69% in public and 36% in private institutions are in rural settings, indicating a larger rural presence. However, urban areas show stronger representation in private enrollments. In terms of teaching staff, rural public schools employ 81% of teachers, whereas urban areas account for a higher percentage in private schools. The distribution of educational institutions, student enrollment, and teachers in middle schools across rural and urban areas for the year 2021-22 is shown in Figure 2.

Figure 2
Geographical Distribution of Educational Institutions, Enrollments, and Teachers (2021-22) (Team, 2024)



Contextualizing STEM Education in Pakistan

STEM education in Pakistan is characterized by a dichotomous structure with public and private schools catering to different socio-economic groups. According to the Pakistan Education Statistics 2021-22 report, middle school education consists of 47,822 institutions throughout Pakistan; 16,238 and 31,584 institutions operate in the public and private sectors, with the majority being private schools (Team, 2024). Despite their more expansive reach, public schools often lack adequate resources and infrastructure to support quality STEM education. In contrast, private schools, while accessible to a smaller segment of the population, generally offer better facilities and a more conducive learning environment for STEM subjects (Awan et al., 2017). However, both sectors have their curses. Public schools lack good teachers, curricula, and labs.

Moreover, examination-oriented learning rather than practical usage and critical thinking is crucial for learning education in STEM (Malik, 2017). The government of Pakistan has also identified a need for STEM education and thus introduced several initiatives to popularize STEM education. These include establishing STEM schools, introducing courses related to it in the curriculum, and providing scholarships to students studying about it (Desk, 2019). However, all these remain to be seen, and many comprehensive and sustained efforts are yet to be made to improve STEM education in Pakistan (Anwar, 2017).

Perception, Engagement, Creativity, and Innovation in STEM Education

The development of STEM education depends on building an executive perception of the STEM area among students (Chen et al., 2024). Research has proven that aspects such as perception about STEM subjects significantly impact student engagement, motivation, and academic achievement (Abdi et al., 2024). Positive perceptions can be built in engaging and relevant classroom activities and real-life applications of concepts created in a supportive learning environment (Council et al., 2012). Engagement is a critical development of innovative skills (Wang, 2019) and reflects the extent to which students are actively involved in learning (Fredricks et al., 2004). More engaged students can be more inquisitive, asking questions, initiating discussions, and seeking further information (O'malley & Chamot, 1990). The deep involvement in learning allows for a deeper understanding of the concepts of STEM that encourages students to go further into the field. Engagement has been linked to deep learning, improved retention of knowledge, and the development of skills in critical thinking (Darling-Hammond et al., 2020; Das et al., 2021). Student engagement is influenced by several factors, including teacher enthusiasm and knowledge, relevance and currency of curriculum, and active and project-based learning activities. The inclusion of project-based learning, in which groups of students address real-world problems, has increased engagement and motivation in the disciplines of STEM (Council et al., 2000).

Creativity and innovation are closely related concepts: creativity refers to the ability to generate new and valuable ideas, while innovation involves applying those ideas to develop new products, processes, or services (Astawan et al., 2023). STEM Education can foster both creativity and innovation by encouraging students to think out of the box, considering multiple solutions to problems, and taking risks. Zakeri et al. (2023) found that implementing STEM activities has encouraged students to develop different non-standard solutions and novel ideas. Susilowati et al. (2020), observed that STEM education activates critical thinking to enhance innovative problem-solving. And Majeed et al. (2021) reported significant improvements in students' creative thinking skills after participating in STEM education programs.

Public vs. Private Schools and Urban vs. Rural Settings in Pakistan

A stark contrast between public and private schools characterizes the Pakistani education system. While public schools, which cater to most of Pakistan's population, have limited resources, outdated infrastructure, and a dearth of skilled teachers (Jstep, 2023), private schools have improved facilities, small class sizes, and skilled teachers (Creative, 2023). These contrasts have a significant bearing on the quality of STEM education in each school (Farooq et al., 2017). A recent systematic literature review carried out by Aslam et al. (2022) reported trends in research in Pakistan's STEM education, citing a lack of resources and awareness in public schools in contrast to private schools.

Similarly, there are vast contrasts between urban and rural schools in Pakistan (Lloyd et al., 2005). Urban schools have improved access to resources and technologies, while rural schools face challenges such as limited connectivity, outdated textbooks, and a shortage of skilled teachers. These disparities can lead to unequal access to opportunities for students in different settings, stifling overall progress in Pakistan's STEM education (R. M. Wood, 2023). A recent research paper carried out by AceLabs emphasized the importance of providing good STEM education to students in rural settings to reduce gaps and improve innovation and economic growth in Pakistan ("Breaking Down Barriers: Revolutionizing STEM Access for Rural Communities," 2024).

While there is increased realization in Pakistan about the importance of STEM education, there is a lack of research on the specific role of STEM education in enhancing students' creativity and innovation. Moreover, there is limited knowledge on how these effects vary across different settings, particularly between public and private schools and urban and rural schools. This research gap restricts our ability to design effective STEM education programs that address the diverse needs of students in Pakistan.

This study aims to bridge this research gap by examining how STEM education influences creativity and innovation in Pakistani middle school students. By comparing public and private schools as well as urban and rural settings, this research seeks to provide a better understanding of the factors that encourage or hinder creativity and innovation in different educational environments.

Research Questions

To address the gaps identified in the literature and to better understand the influence of STEM education on creativity and innovation among middle school students in Pakistan, this study is guided by the following research questions:

1. **RQ1:** How does STEM education influence the development of creativity and innovation among middle school students in Pakistan?

2. **RQ2:** What are the differences in the impact of STEM education on creativity between public and private schools?

3. **RQ3:** How do urban and rural settings differ in terms of STEM education's effectiveness in fostering creative problem-solving skills?

Gender-Based Dimensions in STEM Education

Our analysis reveals that while female students comprise 60.4% of our sample, their engagement in STEM subjects is simultaneously marked by high creativity and cautious optimism, but it is constrained by socio-cultural stereotypes and limited role models, which hinder their long-term participation in these fields (Hollows et al., n.d.). Evidence from nationwide assessments further indicates that although girls often outperform boys in science-related tasks, performance differences in mathematics are less pronounced or even favour boys in certain contexts (Bhutta et al., 2024). In addition, studies examining broader educational trends in Pakistan underscore that systemic gender discrimination—manifested through unequal household resource allocation and persistent cultural norms—continues to impede female advancement in STEM (Pasha, 2023). These challenges are compounded by the scarcity of visible female STEM role models and mentorship opportunities, which are crucial for nurturing self-efficacy and long-term interest in STEM careers. Consequently, addressing these issues through gender-sensitive curricula, enhanced teacher training, and targeted mentorship initiatives is imperative to dismantle prevailing stereotypes and foster a more inclusive STEM environment that fully leverages the potential of both female and male students.

Theoretical Framework

Social Cognitive Theory (SCT), a core pillar in our research framework, defines learning to be a dynamic and bidirectional process between environmental, cognitive, and behavioral factors (Bandura et al., 1986). Bandura developed SCT, a rich theory through which we can interpret how students' perceptions, engagement, and performance in STEM education are formed and affected. SCT highlights that learning is not an individual process but one within a social setup, highly influenced by observing other individuals' behavior, attitudes, and outcomes (Bandura, 2001). Self-efficacy, in Bandura's SCT, has a significant role in influencing students' academic and professional decisions, and research has established that gender differences in STEM self-efficacy, in math and science classes, emerge early and persist, influencing academic performance and feedback responses (Stewart et al., 2020).

Our research investigates various aspects of SCT, starting with observational learning. This SCT aspect is concerned with modeling in learning, whereby students learn from observing what their peers and teachers do and what happens to them (Bransford et al., 2005). To measure this process, our survey questions were designed to assess the extent and nature of exposure students have to STEM activities and what they perceive about them. We were particularly interested in role models and how peers and teachers who themselves are working in and promoting STEM can have a big role in influencing students' engagement and interest in such fields (Usher & Pajares, 2008). Survey results provide insights into how observational learning influences students' attitudes towards STEM and their engagement in related activities.

Another crucial aspect of SCT that is explored in our research is reciprocal determinism (Wood & Bandura, 1989). This concept highlights the bidirectional influence between personal factors, behaviors, and the environment. Specifically, our research investigates how students' beliefs about their capabilities in STEM affect their engagement in these subjects and how their engagement and experiences in STEM influence their self-efficacy. The survey questions addressing reciprocal determinism were crafted to uncover these intricate interactions. By analyzing these responses, we elucidate how students' confidence in their abilities (a personal factor) interacts with their behaviors (engagement in STEM activities) and the educational environment, creating a cyclical pattern that can either bolster or hinder their academic journey in STEM (Pajares, 1996).

A pivotal construct within SCT that our study focuses on is self-efficacy, which refers to an individual's belief in their capacity to execute tasks and achieve goals (Bandura, 1997). In STEM education, self-efficacy is a crucial determinant of students' willingness to tackle challenging projects and their perseverance in problem-solving tasks (Zimmerman, 2000). Our self-efficacy survey items were designed to gauge students' confidence in their ability to succeed in STEM-related tasks. This includes their perceived competence in handling specific STEM projects and problem-solving skills. Understanding self-efficacy levels among students provides valuable insights into their motivation and persistence in STEM fields, which are essential for their long-term success and interest in these areas (Lent et al., 1994).

Drawing on social cognitive theory, our study investigates complex aspects of observational learning, reciprocal determinism, and self-efficacy related to STEM education. By investigating how students' exposure to role models, their personal beliefs of capability, and recursive interaction between behaviors and environment influence their engagement in and outcomes from STEM, the study identifies strategies to improve STEM education and support the development of a science-capable and science-literate generation. The insights from this research work can highlight key factors shaping students' intentions and engagement in STEM, offering educators, policymakers, and curriculum developers valuable guidance for advancing the best practices in STEM education.

STEM Education in Pakistan: Program Structure, Activities, and Challenges

A representative STEM program in Pakistan typically integrates theoretical instruction with hands-on, experiential learning to foster critical thinking and innovation, although significant disparities exist between public and private schools. In private institutions, STEM curricula are often delivered through an interdisciplinary approach that combines project-based learning, laboratory experiments, coding, robotics, and design thinking exercises to create a dynamic, student-centered learning environment (Awan et al., 2017; Thomason & Hsu, 2024). In contrast, public schools have a more traditional, exam-based system with restricted access to state-of-the-art laboratories and technological resources, restricting frequency and scope for hands-on STEM activities (Malik, 2017; Team, 2024). To address these imbalances, recent government initiatives, such as the National STEM Schools Project, have piloted better STEM programs in a small subset of public schools through science laboratory renovations and specialized teacher training (Anwar, 2017; Desk, 2019). Despite these initiatives, ongoing resource constraints and sociocultural challenges—especially in rural areas—continue to hinder the effective implementation of STEM education. This emphasizes the need for stronger policy interventions to ensure equitable access to high-quality STEM programs across all learning contexts (Nazli & Noman, 2023; Wood, 2023).

Research Methodology

Survey Design

The research design utilized in this study is cross-sectional, which allows for a snapshot to be taken of middle-grade students' engagement, creativity, and innovation in STEM Education, and their perceptions about STEM education from all over Pakistan. This design allowed for data collection from a wide range of the student population all at once.

Online survey mode was selected due to its efficiency and ability to reach a geographically dispersed sample. Easy-to-use interfaces, instructions, and required validation checks were all incorporated in the design to deliver high-quality data. This was selected to maximize response rates and to make the instrument accessible and engaging to middle school students with different backgrounds.

Perceptions of STEM Education

We included items in the questionnaires on how students perceived the relevance and usefulness of STEM subjects to assess their perceptions of the relevance and usefulness of learning STEM subjects. These items were intended to capture students' perceptions of the role of STEM subjects in developing critical thinking, problem-solving, and communicative competencies. Additionally, we queried students' perceptions about career opportunities in STEM fields to assess how they perceive their study of a STEM discipline as a way to obtain employment and capitalize on personal development. These are necessary to pinpoint misconceptions or knowledge gaps that can be addressed by proper educational intervention.

Engagement in STEM Activities

To understand students' engagement with STEM in and beyond the classroom, we surveyed the frequency and type of students' engagement in hands-on experiments in science, technology, engineering, and math, how technology was integrated into their STEM subjects, and whether students took part in extracurricular activities related to STEM. We investigated how frequently students engage in practical experiments at school, as these activities play an important role in supporting the teaching and learning of science concepts through real-world application. We also looked into integrating technology into a student's learning process about STEM subjects, considering the importance of technology integration in contemporary education. Further, questions related to extracurricular activities aimed at establishing students' interest in STEM and a willingness to support it outside of school hours.

Creativity and Innovation

Another essential dimension measured in our questionnaire was students' confidence in creative skills within STEM contexts. Items captured students' enjoyment of innovative problem-solving, their willingness to take on challenges, and their comfort with open-ended problems requiring creative solutions. The survey also included questions about experiences with projects that foster creativity, such as designing experiments, developing new technologies, or working in maker spaces. These responses provided insights into whether students viewed themselves as creative and enjoyed the opportunity for innovation — factors that are critical for supporting students in developing the creative thinking skills essential for future careers in the STEM disciplines.

Our research design is empirically structured to comprehensively analyze the engagement, creativity, innovation, and perceptions of middle school students regarding STEM education across Pakistan. In this process, we investigated key themes that provided us with valuable data related to the current strengths. The analysis also allowed us to identify areas for improvement in the STEM curriculum that may be used in bolstering several educational experiences for educators, policymakers, and developers. This would eventually develop better STEM education practices and mold the psyche of a generation of students who, though knowledgeable in the subjects, were confident, creative, and innovative thinkers.

Population and Sampling

Our sample consisted of middle school students in grades 6 to 8 in Pakistan, selected from schools with a STEM-related curriculum or extracurricular programs. This criterion ensured that all participants had prior exposure to STEM education, making their responses directly relevant to the study. Students outside grades 6 to 8, as well as those from schools with no STEM-related offerings, were excluded to maintain a focused and comparable sample.

To achieve representativeness and diversity, we employed a stratified random sampling method. Student populations were stratified in terms of geographical area (urban/rural) and school type (public or private). This was to control for variations in educational contexts and resources in different geographical locations and school environments.

The stratified random sampling method was chosen in particular to ensure that our sample is representative of Pakistan's diverse socio-economic and educational contexts. We ensured proportionate representation from each subgroup via stratification along urban/rural region and public/private school affiliation. This research design move enhances the external validity of our findings and allows for a more nuanced comparison between Pakistan's heterogeneous educational contexts.

Data Collection

Data was gathered through an online survey, chosen for its flexibility and ability to reach a large and diverse student body across Pakistan. This approach overcame geographical and infrastructural barriers by allowing remote submissions from both urban and rural settings, while also providing a standardized and cost-effective tool for large-scale educational research (Afzal et al., 2024). We designed the questionnaire to be user-friendly, with simple and clear instructions, easy navigation, and interactive elements. It was also optimized for multiple devices — including computers, tablets, and smartphones — to accomodate varying levels of technological proficiency. Additionally, obligatory fields and validation checks were introduced to minimize incomplete or erroneous responses, enhancing the accuracy and quality of the data.

Reliability and Validity

Reliability was established through Cronbach's Alpha, a widely used measure of internal consistency. High Cronbach's Alpha values indicate strong internal consistency across survey items (Gong et al., 2024; Hajjar, 2018). Our obtained value of 0.9655 demonstrated excellent internal consistency among survey items, confirming that the instrument reliably measures student engagement, creativity, innovation, and perceptions regarding STEM education.

To further establish construct validity, Principal Component Analysis (PCA) was conducted, a robust statistical technique for data reduction while maximizing variance retention. In our study, the Scree polt showed a distinct "elbow" after the second component, leading us to extract only two principal components, which accounted for 62.2% and 5.9% of total variance, respectively. These components captured the dominant underlying factors pertinent to our study — primarily student engagement and perceptions toward STEM education. Combined with a high Cronbach's Alpha, the variance captured by these components reinforces our measurement instrument's internal consistency and construct validity.

The selection of PCA, along with other methods employed in this study, was driven by the need to ensure that the most salient aspects of the data were accurately represented while minimizing redundancy. The Scree plot analysis justified the decision to focus on two principal components, which clearly demonstrated a significant drop in the eigenvalues beyond the second component. This approach ensures that our analysis remains both parsimonious and theoretically meaningful.

Data Analysis

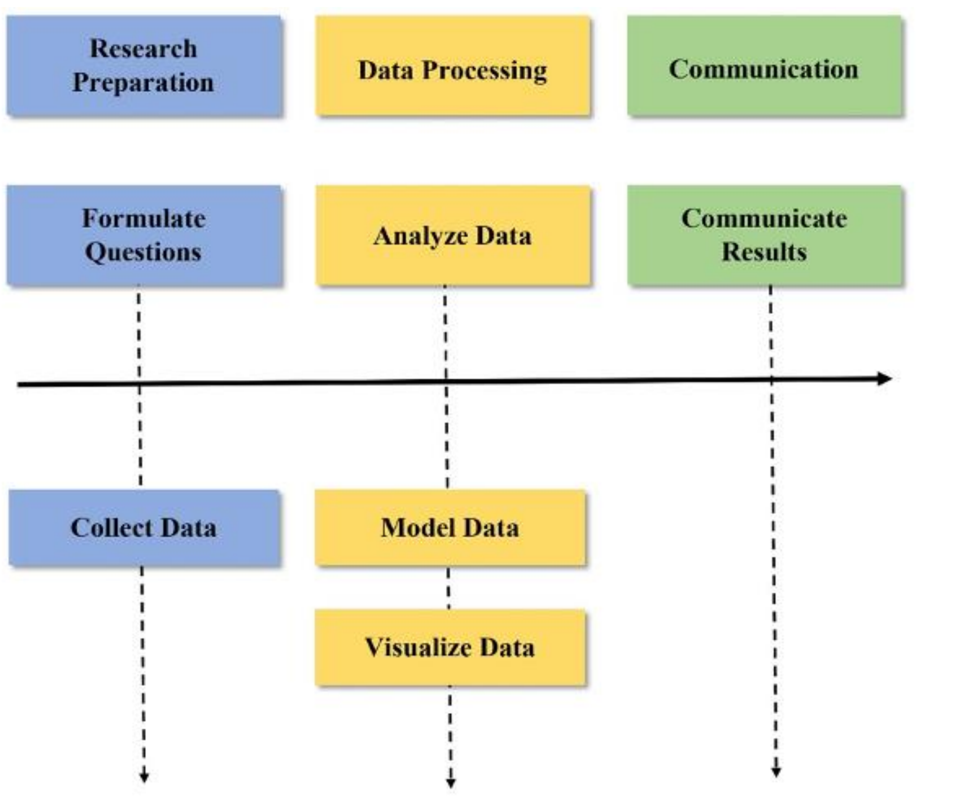
Descriptive statistics provided a summary of the data in terms of the overall distribution and general patterns of the data set. These included measures of central tendency, such as means, and variability, such as standard deviation. The mean represented the average value for each survey item, serving as the center of gravity for the data, while the standard deviation indicated how much individual values deviated from this average. By capturing key trends and patterns, descriptive statistics allowed the researchers to identify common responses as well as outliers. This analysis, simple yet essential, preceded higher-order statistical procedures once the primary features of the data were established.

The general workflow used in processing the data is illustrated in Figure 3, promoting transparency and reproducibility. It comprised three stages: Research Preparation, Data Processing, and Communication. In the Research Preparation stage, we developed the research questions necessary to conduct the research work and data collection methods aligned with the variables of interest. During the data processing phase, the data were analyzed using appropriate statistical methods. Summary statistics were calculated through descriptive analysis, and advanced statistical modeling techniques were applied to examine deeper relationships and patterns in the data. Data visualization tools, including charts and graphs, were then used to facilitate interpretation and presentation. During the Communication stage, findings were synthesized into clear, detailed reports with visual aids to effectively communicate the results to stakeholders.

Descriptive statistics were systematically applied within this structured workflow to create a detailed summary of student responses, ensuring that analyses were thorough, findings were robust, and a solid foundation was established for further statistical analysis and interpretation.

Figure 3

Data Processing Workflow for Analyzing STEM Engagement



Ethical Considerations

Before data collection, procedures for research were established to safeguard all participants' rights and welfare. Due to the research being carried out with middle school students who are minors, informed consent was obtained in a two-step process with minors and their parents or legal guardians. Detailed information sheets explaining the purposes, procedures, potential risks, and voluntary nature of participating in research were provided. This ensured that both minors and their guardians fully understood the study and their rights, including the ability to withdraw at any point in time without consequences. Additionally, no personal identifying information was obtained from students, ensuring total anonymity throughout the research process.

It should be pointed out that, in line with guidelines from the institution and in light of the non-invasive nature of this research, a formal institutional review board (IRB) approval was not necessary. Research was conducted within standard educational research procedures and was deemed to present minimal risk to participants. Nonetheless, all ethical considerations were observed in every aspect of research, with rigorous measures to maintain participant anonymity and data security. All data obtained were kept securely and only shared with members of the research team.

While this study is quantitatively driven to assess the role of STEM education, further use of qualitative measures, such as in-depth interviews or focus groups, would better capture student experience and contextual factors influencing engagement in STEM. Mixed-method designs are recommended for future studies to better capture the complexities in learning environments.

Results

Demographic Characteristics

We studied and analyzed data from 164 middle school students in Pakistan, considering various demographic backgrounds, including gender, location, and school type, to assess the impact of STEM education across different groups. This approach allowed us to understand how various demographic factors influence students' engagement and perceptions of STEM education.

Table 1

Demographic Characteristics of Middle School Students in Pakistan (N=164)

Category	Sub-category	Frequency	Percentage(%)
Age Group	11-12 years	70	42.7
	13-14 years	94	57.3
Gender	Female	99	60.4
	Male	65	39.6
Location	Urban	100	61.0
	Rural	64	39.0
School Type	Public	76	46.3

Private	88	53.7

Table 1 presents the demographic characteristics of the sample, comprised of 99 females (60.4%) and 65 males (39.6%), with 70 students aged 11–12 years (42.7%) and 94 students aged 13–14 years (57.3%). In terms of location, 100 students (61%) are from urban areas, while 64 (39%) are from rural areas. Furthermore, 76 students (46.3%) attend public schools, and 88 (53.7%) attend private schools.

The diverse demographic composition — highlighting a higher proportion of female students and balanced urban–rural and public–private representation — provides a robust foundation for understanding how varied educational settings and sociocultural contexts influence STEM engagement and creative outcomes. This heterogeneity is crucial for drawing nuanced conclusions about the differential impacts of STEM education in Pakistan.

Perceptions of STEM Education

Students held highly positive perceptions regarding the benefits of STEM education in developing crucial skills. A majority, 54.3%, strongly agree that STEM education stimulates curiosity and exploration. Additionally, 54.9% strongly believe it enhances problem-solving skills, and a slightly higher percentage, 59.1%, feel it encourages critical thinking abilities. Moreover, 56.7% strongly agree that STEM education improves collaboration and teamwork skills, while 52.4% believe it enhances communication skills.

Table 2

Descriptive Statistics of Student Perceptions on STEM Education

Aspect	Urban Mean (SD)	Rural Mean (SD)	Private Mean (SD)	Public Mean (SD)
Promotes Curiosity and Exploration	4.25 (1.10)	4.05 (1.17)	4.30 (1.08)	4.05 (1.18)
Encourages Problem-Solving Skills	4.32 (1.02)	4.11 (1.10)	4.35 (1.02)	4.10 (1.09)
Encourages Critical Thinking Abilities	4.35 (0.99)	4.21 (1.05)	4.38 (0.97)	4.20 (1.05)
Enhances Collaboration and Teamwork	4.18 (1.15)	4.08 (1.20)	4.22 (1.10)	4.10 (1.20)
Improves Communication Skills	4.15 (1.22)	3.92 (1.24)	4.17 (1.21)	3.93 (1.24)

Table 2 summarizes the descriptive statistics of student perceptions regarding various aspects of STEM education. For instance, scores on "Promotes Curiosity and Exploration" indicate a mean of 4.25 (SD = 1.10) for urban students versus 4.05 (SD = 1.17) for rural students. Similar trends appear for problem-solving, critical thinking, collaboration, and communication skills.

The data reveal that urban and private school students consistently report higher mean scores in key areas such as curiosity, problem-solving, and critical thinking. This suggests that resource-rich environments foster stronger positive perceptions of STEM education and enhance the foundational skills necessary for creative and innovative thinking. In simple terms, when students are taught in settings that encourage exploration and hands-on learning, they feel more confident and better prepared to tackle real-world challenges. These findings directly address RQ1 by demonstrating that effective STEM education is pivotal in nurturing creativity and critical thinking.

Engagement in STEM Learning Activities

The assessment of student engagement in STEM-related activities reveals significant participation across different settings. Among students surveyed, a majority showed high levels of involvement in hands-on experiments or projects (56.1%), frequently collaborating with peers on STEM tasks (53%), utilizing technology tools or software (51.8%), attending STEM workshops, events, or competitions (51.8%), and exploring STEM resources outside of school (51.2%). Descriptive statistics further illustrate these trends: urban students reported slightly higher mean scores across all categories than rural counterparts, with private school students consistently indicating marginally higher engagement levels than public school students. These findings underscore a robust interest and active participation in STEM learning among students, reflecting varied levels of engagement influenced by educational context.

Table 3

Descriptive Statistics of Student Engagement in STEM Learning Activities

Aspect	Urban Mean (SD)	Rural Mean (SD)	Private Mean (SD)	Public Mean (SD)
Hands-on Experiments	4.20 (1.20)	3.98 (1.27)	4.25 (1.19)	3.96 (1.28)
Collaborating with Peers	4.22 (1.10)	4.08 (1.17)	4.27 (1.10)	4.03 (1.17)
Using Technology Tools	4.20 (1.15)	4.02 (1.18)	4.24 (1.14)	4.00 (1.18)
Attending STEM Workshops	4.10 (1.23)	3.92 (1.26)	4.14 (1.21)	3.91 (1.27)
Exploring STEM Resources	4.05 (1.20)	3.88 (1.25)	4.09 (1.22)	3.87 (1.26)

Table 3 summarizes student engagement across various STEM activities. For example, the mean score for participation in hands-on experiments is 4.20 (SD = 1.20) among urban students compared to 3.98 (SD = 1.27) for rural students, with similar differences noted in collaborative work, technology use, attendance at STEM workshops, and exploration of STEM resources. Higher engagement scores among urban and private school students underscore the critical role that enhanced facilities, better access to technology, and interactive teaching methods play in driving active participation. In practical terms, this means that students who are exposed to more dynamic and resourceful learning environments are more likely to be involved in STEM activities, which, in turn, builds their problem-solving and innovation capacities. This directly supports RQ3 by illustrating that geographical and institutional contexts significantly influence how effectively STEM education fosters creative problem-solving skills.

Table 4 reports on aspects of creativity and innovation, including confidence in generating new ideas, exploring innovative solutions, interest in STEM careers, and improvements in problem-solving and critical thinking. Urban students, for instance, report a mean confidence score of 4.22 (SD = 1.05) compared to 4.07 (SD = 1.09) for rural students, with private schools showing similar positive trends over public schools.

The results indicate that students in urban and private settings not only feel more confident in generating new ideas but also show a stronger inclination toward pursuing STEM careers. In other words, these students are more likely to see themselves as innovators and future leaders. This enhanced creativity and innovation is the direct outcome of engaging STEM curricula that emphasize hands-on experiments, collaborative projects, and the effective use of technology. In relation to RQ2, the insights suggest that differences in resources and teaching methods between private and public schools significantly shape students' creative outcomes and career aspirations.

Table 4
Descriptive Statistics of Student Creativity and Innovation Skills in STEM Contexts

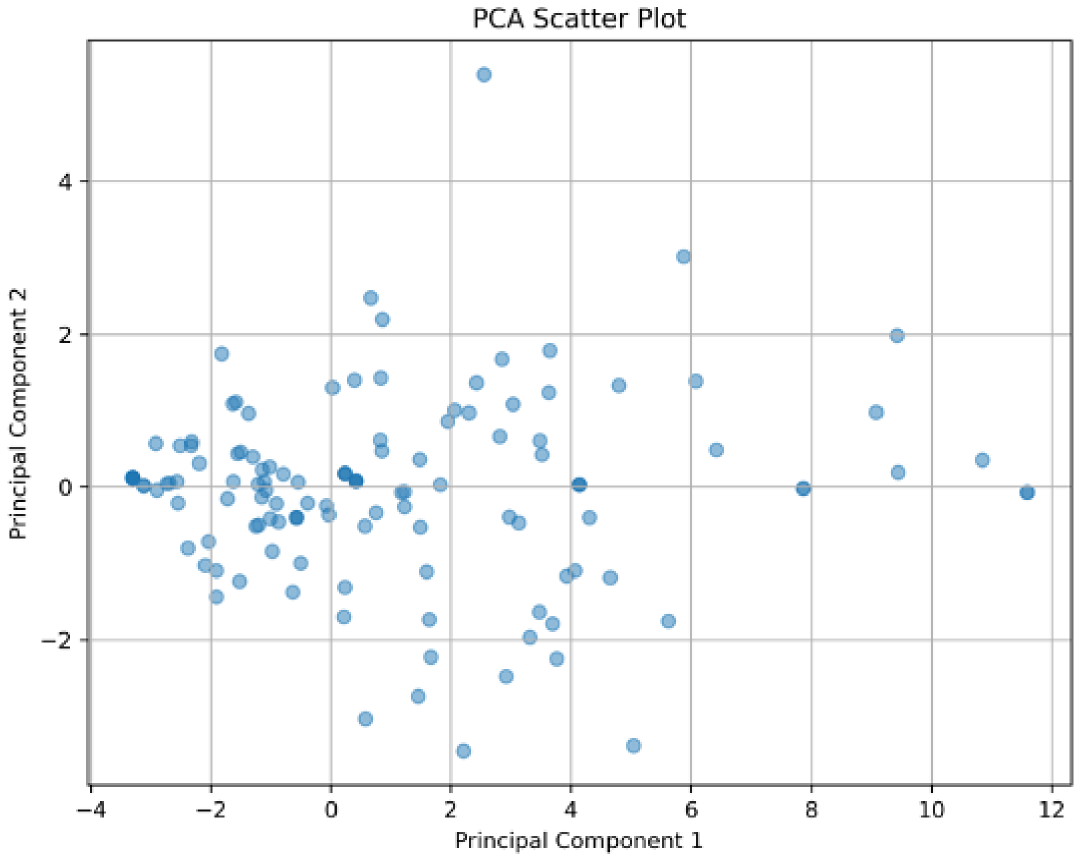
Aspect	Urban Mean (SD)	Rural Mean (SD)	Private Mean (SD)	Public Mean (SD)
Confident in Ideas	4.22 (1.05)	4.07 (1.09)	4.27 (1.04)	4.04 (1.08)
Exploring Innovative Solutions	4.32 (1.01)	4.17 (1.06)	4.34 (1.00)	4.15 (1.06)
Interest in STEM Careers	4.10 (1.30)	3.89 (1.34)	4.15 (1.29)	3.86 (1.34)
Improve Problem-Solving Skills	4.16 (1.18)	4.00 (1.20)	4.19 (1.17)	3.98 (1.19)
Enhanced Critical and Analytical Thinking	4.18 (1.22)	4.00 (1.25)	4.21 (1.20)	3.99 (1.23)

Reliability and Validity Analysis

The questionnaire's reliability was assessed using Cronbach's Alpha, which yielded an outstanding value of 0.9655, indicating excellent internal consistency among the items. This suggests that the questionnaire items consistently measure the intended constructs, effectively capturing the dimensions of students' engagement, creativity, innovation, and perceptions regarding STEM education.

Figure 4

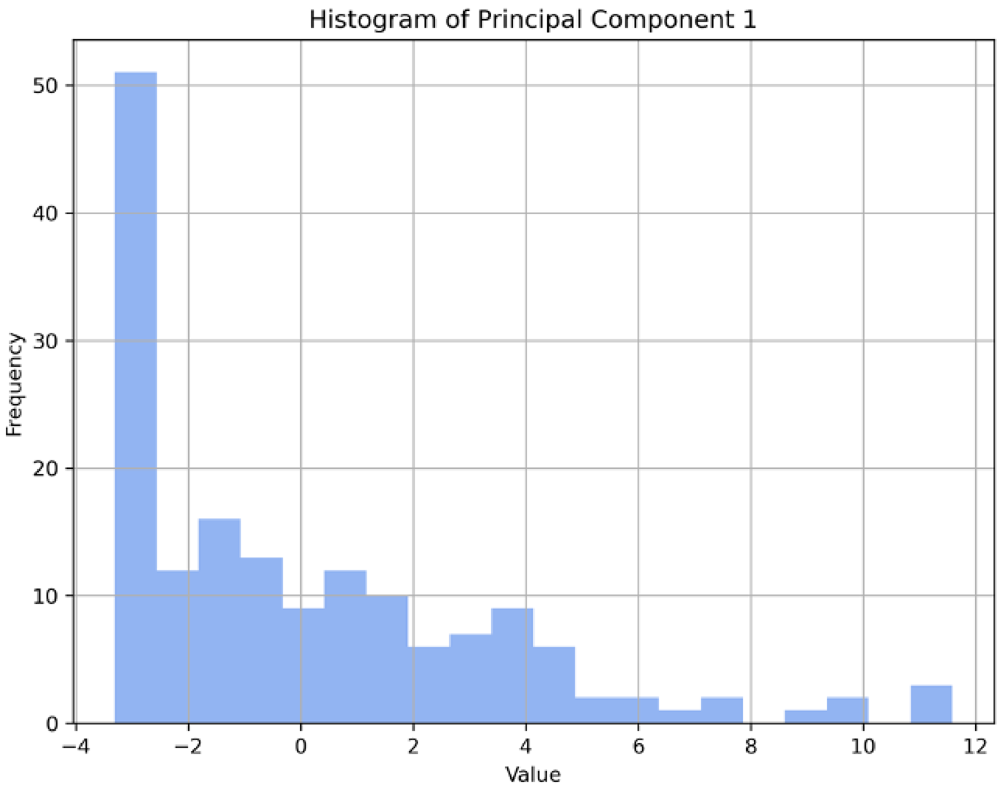
PCA Scatter Plot: Clustering of Student Response Patterns



Principal Component Analysis (PCA) was conducted to examine the construct validity of the questionnaire. PCA is a statistical technique used to reduce the dimensionality of data while preserving as much variability as possible (Yesilkaya et al., 2023). The Scree plot, Figure 6 indicated that two principal components should be retained, which together explained 62.2% and 5.9% of the total variance, respectively. The first component, accounting for a substantial proportion of the total variance, suggests that the questionnaire items measure a dominant underlying factor — likely representing the core aspects of students' engagement and perceptions towards STEM education. Figures 4 and 5 further illustrate the clustering of responses and the distribution of scores along the primary component, respectively.

Figure 5

Histogram of Principal Component 1: Distribution of Engagement and Perception Scores



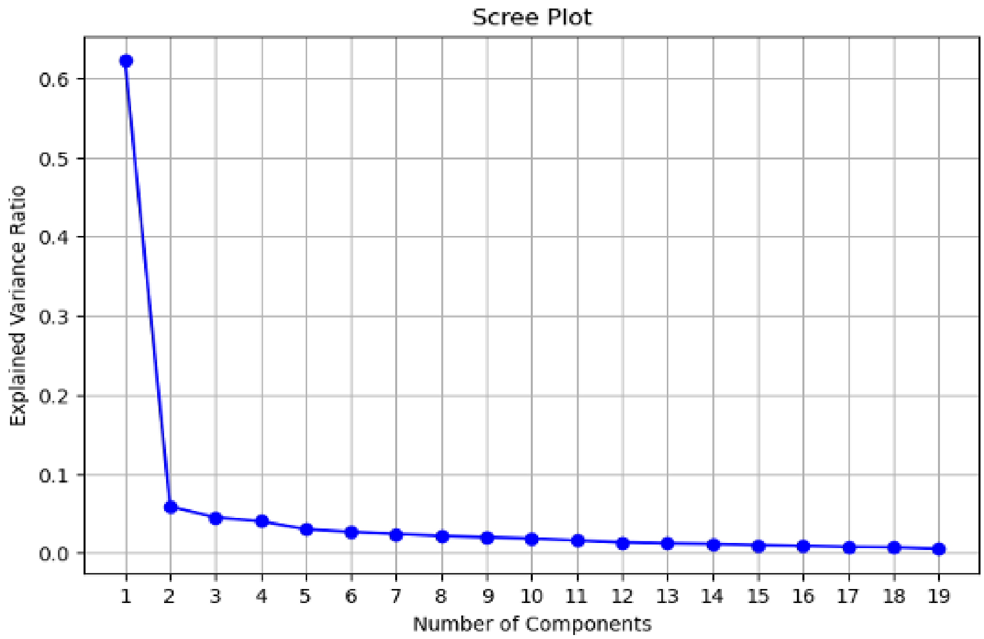
The exceptional reliability and the clarity offered by the PCA results not only validate our measurement tool but also reinforce the trustworthiness of the data. In layman's terms, the survey effectively captures the key dimensions of STEM engagement and creativity, ensuring that our subsequent interpretations and policy recommendations are built on a solid empirical foundation.

Integration of Findings and Addressing Research Questions

Our findings provide compelling evidence that STEM education significantly enhances students' creativity, problem-solving, and critical thinking skills (RQ1). Moreover, our data indicate that private schools- presumably benefiting from superior resources and more innovative pedagogical practices- yield more pronounced positive outcomes than public schools (RQ2). In addition, the elevated levels of engagement and creative outputs observed among urban students underscore the critical role that modern educational infrastructure plays in fostering creative problem-solving abilities (RQ3). These results not only substantiate the theoretical framework underpinning our study but also underscore the urgent need for targeted policy interventions to mitigate educational disparities across Pakistan.

Figure 6

Scree Plot: Eigenvalue Distribution of Principal Components



Discussion

Our findings provide critical insights into the state of STEM education in Pakistani middle schools, highlighting both its benefits and existing disparities. Students generally hold positive perceptions of STEM education, recognizing its role in enhancing essential skills such as curiosity, problem-solving, critical thinking, collaboration, and communication. These perceptions directly influence students' engagement and long-term interest in STEM fields. High levels of engagement, particularly in practical activities, were found to significantly strengthen students' interest and sustained participation in STEM learning.

Experiments and projects that are carried out in collaboration make clear the effectiveness of interactive and experiential learning of these skills. In the era of AI, the integration of technology in education — through e-learning tools during COVID-19 (Das et al., 2021), immersive STEM learning (Chng et al., 2023), Urdu Sign Language translation (Das et al., 2024), and predictive modeling techniques (Abdrakhmanov et al., 2024; Das, 2024; Dutta et al., 2025; Yang, 2022) — demonstrates its transformative role in addressing educational challenges.

However, our research has indicated significant differences in STEM education outcomes across educational setting. Students from urban settings consistently reported higher engagement and positive perceptions than their rural counterparts. Similarly, students from private schools were more engaged and showed greater perceived benefits from learning STEM subjects than their public school counterparts. These disparities reflect the broader socio-economic and infrastructural challenges faced by rural and public schools in Pakistan. Urban and private schools generally benefit from better resources, more qualified teachers, and curricula aligned with modern educational needs, while rural and public schools remain underfunded, rely on outdated teaching methods, and lack essential resources such as laboratories and technology.

These discrepancies must be addressed to ensure equitable access to quality STEM education for all students. Closing resource and infrastructure gaps in rural and public schools is especially critical. This requires government funding, upgraded facilities, teacher training in modern pedagogy, and providing essential resources for learning, engineering, technology, and mathematics. Partnerships with private organizations and NGOs can further supplement and support these efforts.

Improvement in the quality of STEM education at the school and college level would not only enhance student performance but also contribute to regional development, fostering innovation and economic growth. Our findings also underscore the importance of including STEM-based coursework within the middle school curriculum. Incorporating hands-on laboratory experiments, group projects, and problem-solving drills into the curriculum will help instructors develop more active and pertinent learning environments. Such approaches align with constructivist theories of learning, which emphasize experiential methods for building problem-solving and critical thinking skills. Ultimately, these efforts will better prepare students with the competencies needed to thrive in a rapidly changing 21st-century world.

Policy Recommendation

The wide diffusion of best practices in STEM calls for policy enhancements that prioritize providing educators with resources, followed by training on how to implement STEM practices. This should include professional development programs on current STEM teaching methods, the integration of technology in education, and strategies to foster creativity and innovation. Curriculum developers should also work to align the national curriculum with global STEM standards, ensuring that students are exposed to the latest technologies and best practices.

To fully realize the benefits of STEM education, schools must foster supportive learning environments that encourage inquiry, experimentation, and risk-taking. Teachers play a pivotal role since their enthusiasm and expertise go a long way in influencing students' attitudes toward STEM subjects. In addition, schools should create opportunities for extracurricular engagement in STEM activities like clubs, competitions, and workshops, to further cultivate their interests and skills.

Limitations and Future Research

Despite these findings, there are various limitations in our study that need to be overcome in future research. The reliance on self-report data introduces the possibility of bias, as responses may be influenced by social desirability or other factors. Added to this is the fact that the cross-sectional nature of our present study limits our ability to draw inferences about causality. Longitudinal studies are needed to probe the impacts of STEM education on students' long-term creativity, innovation, and career trajectories. Qualitative methods such as interviews and focus groups could provide even deeper insight. The interviews will yield information on experiences and student perceptions that might give an understanding of factors deeper than those involved in students' STEM education engagement and outcomes.

Conclusion

The study depicts evidence of how STEM education instills creativity, critical thinking, and problem-solving skills in students during middle school in Pakistan. It was observed through various test results that active engagement in different STEM activities increased the capability of students to think more critically, approach problems in a creative manner, and function well within a team. These skills are significant for preparing students to meet the challenges of the 21st century and to compete in the global labor market, underlining the transformational potential of STEM education.

At the same time, the research highlights significant inequalities in the quality of STEM education across different educational contexts. A clear urban-rural divide was observed: schools in urban areas benefit from better resources, qualified teachers, and modern teaching methods, leading to greater student motivation and more positive perceptions of STEM. On the other hand, rural schools often face inadequate infrastructure, outdated teaching practices, and a lack of STEM facilities, which hinder student learning. Bridging this gap will require targeted investments in rural education, facility improvement, expanded access to technology, and ongoing teacher training.

Public vs. Private School Differences

Private schools consistently achieve higher in STEM subjects than their public peers. The reasons are, among others, smaller class sizes, better-trained educators, and curricula that are often more closely aligned with international standards. Public schools struggle with outdated curricula, scarce finances, and limited extracurricular opportunities for STEM subjects. For the gap to be bridged, there must be government policy reforms, more funding in public education, and public-private partnerships for resource and expertise sharing.

Gaps in the Curriculum

Most STEM curricula within schools are not designed to emphasize creativity and innovation. Most teaching remains examination-oriented, restricting the exploratory and practical modes of learning in students. In this particular environment, experiential learning—through project-oriented assignments, teamwork, and problem-solving activities—can be ignited with the aim of fostering creative thinking. These changes would require curriculum developers to revise existing standards and incorporate interdisciplinary approaches to learning.

The Role of the Teachers

Effective STEM education depends on well-trained educators who foster curiosity and support continuous exploration and inquiry. New innovative STEM pedagogies should be stressed during professional development, such as using technology effectively, project-based learning, and fostering critical thinking. This will eventually equip educators with the ability to shift away from rote learning toward a more dynamic classroom environment.

This can be achieved with the incorporation and development of STEM in middle school education in Pakistan, which is a crucial factor in motivating the ‘future innovators and leaders.’ This study has brought to the limelight the need for multidimensional reforms, including curriculum revision, targeted investments, enhanced teacher training, and policies to reduce disparities and create a more inclusive and practical framework for STEM education. These changes can empower a new generation capable of making meaningful contributions to Pakistan’s technological, economic, and social sustainable development.

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Author's Notes

Kamlish
ORCiD: 0009-0003-3526-0945
National University of Sciences and Technology (NUST), Pakistan
Email: kamlish@outlook.com

Khushal Das
ORCiD: 0000-0001-8833-0888
University of Calabria, Rende (CS), Italy
Email: khushal.das@dimes.unical.it