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RESEARCH PAPER

An Analysis of STEM Education Competencies: Assessing Knowledge and Attitudes among Teacher Trainers and Teacher Trainees

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ABSTRACT

The world is frequently facing major economic and environmental crises. It is the need of the hour to develop the right skills in the 21st century by bringing technology in the schooling landscape right from early childhood education through various pedagogical frameworks. Science, Technology, Engineering and Mathematics (STEM) is the pedagogical approach used across the globe to transform nations towards innovation-led entrepreneurial economy. The present study was conducted to analyze the knowledge and attitude of teacher trainer and trainees in the context of STEM education. The study was based on quantitative research and the data were collected using validated instruments: STEM Pedagogical Content Knowledge (STEM-PCK) and Attitude Towards STEM (AT-STEM) questionnaires, with reliability scores ($\alpha = 0.92$ and $\alpha = 0.82$, respectively). The sample included 75 teacher trainers and 172 trainees selected through simple random sampling. Data analysis was done using SPSS 21, employing descriptive statistics; mean and SD to analyze knowledge and attitudes. Results indicated that both trainers and trainees possessed moderate knowledge in most STEM domains, though mathematics knowledge was notably low in both groups. Trainees showed slightly higher pedagogical knowledge and 21st-century skills compared to trainers. Attitudinally, both groups expressed positive dispositions towards STEM education. Based on the findings, it is recommended that STEM teacher training programs may incorporate context-based, interdisciplinary content with a special focus on mathematics and engineering, alongside the integration of digital tools and flexible, differentiated learning strategies. Professional development may be ongoing, inclusive, and contextual to teachers' backgrounds, promoting conceptual clarity, confidence, and real-world application.

KEYWORDS STEM Education, Teacher Trainers, Teacher Trainees, Stem-Attitude, STEM-Knowledge, STEM Competencies

Introduction

Science, Technology, Engineering and Mathematics (STEM) Education unifies four academic fields and this idea actually emerged in the in the United States through educational policy in the 1990s through National Science Foundation (Diana et al., 2021). STEM Education propose various combinations of the discipline such as emphasizing science and mathematics with technology and engineering, integrating each subject into another, or combining all other STEM disciplines (Aslam et al., 2018). Furthermore, STEM education is prioritized on national agendas in many countries throughout the world, especially in the industrialized and wealthy developed nations (Al Basha, 2018). The concept of STEM education has been addressed in the USA since the 1990s but few teachers appeared to be less knowledgeable about it even several decades after (Kelley &

Knowles, 2016). The release of multiple important papers in the early 2000s led to a rapid rise in the integration of the STEM disciplines in the United States.

Pakistan was ranked second last in Trends in International Mathematics and Science Study (TIMSS) acquiring the lowest benchmark internationally for math and science, it is alarming and imperative to improve the quality of education in math and science disciplines in Pakistan (TIMSS & PIRLS International Study Center at Boston College, 2019). Intense competition in the international business, technological, industrial and educational spheres in the world, STEM education has recently received a lot of attention. STEM education has emerged as a means of meeting industrial demands and developing STEM-capable workers. The legislative shift in the country has encouraged to fund STEM education rapidly which can be visibly depicted in National Curriculum of Pakistan. There is a need for more schools with suitable blended learning facilities, more instructors with understanding of STEM teaching resources such as project-based math and science units, visual ranking reasoning and providing evsidence tools, and so on, as well as abilities in online teaching and blended learning (Ministry of Science and Technology, 2022).

Pakistan stood second last in the TIMSS report achieving the lowest benchmark in science and mathematics internationally raised questions on the quality of Mathematics and Science curriculum and the quality of teaching in Pakistan (Ahmad et al., 2022). The STEM education is recently introduced in Grade 4th to 8th National Curriculum of Pakistan (*Ministry of Federal Education and Professional Training*, 2022). The benchmarks, strands, crosscutting elements and student learning outcome have been set for the implementation of STEM Education in Pakistan. The policy emphasizes increased creation of high-quality human resources at all levels in order to meet international standards. STEM education at the primary, secondary, and postsecondary levels is being emphasized, with the goal of producing industry-ready people resources (Ministry of Science and Technology, 2022).

The proposed study intends to analyze the in-service teacher trainers' and trainees' knowledge and attitudes in the context of STEM. The proposed study intends to explore the relationship between knowledge and attitude of the in-service teacher trainers' and trainees' in the context of STEM. The intended study proposes to fill the methodological gaps between research and practice in the field of STEM education as comparatively very less research has been conducted in Pakistani context particularly, for in-service teacher trainers and trainees' competencies and challenges in the context of STEM education.

Conceptual Framework

The capacity of an individual to effectively use STEM knowledge, attitude and abilities in one's everyday life or in an educational setting is known as STEM competency (Yuan & Ronghua, 2022). It is important to invest in the training of prospective STEM educators so they have the knowledge and abilities needed to succeed in their field thriving in this new pedagogical trend. The conceptual framework for this study is based on two domains which reflect the overall competencies and challenges for STEM education. The first of two variables used in this proposed study comprises STEM Knowledge and Attitude towards STEM. Knowledge and attitude are linked and impact one another. Facts and concepts learned may also affect our sentiments and emotions, and vice versa. Whereas the third variable includes STEM challenges including intrinsic and extrinsic challenges faced by the teacher trainers' and trainees' in the training of

STEM. Stating from the very first variable that is STEM Knowledge is mostly comprised of concepts, theories, and principles related to STEM (Ismail et al., 2019). Shulman (1986) emphasized on gaining information that enables teachers to properly relate to their topics or particular subjects are necessary building a linkage between content and pedagogy. Content Knowledge of concepts basically includes theories, ideas; subject knowledge and the knowledge production process are some of the components that make up this knowledge whereas the Pedagogical Content Knowledge (PCK) is defined as the exposition of the subject knowledge with suitable teaching method according to the demand and need of the learners (Mishra & Koehler, 2006). Durak et al. (2022) focused on the STEM-PCK of teachers and related it with 21st century skills of creativity, communication, collaboration and critical thinking which are regarded as an important component for teachers' knowledge on STEM. Keeping the literature cited the knowledge component for STEM teachers include three sub domains that are Content knowledge, pedagogical knowledge and 21st century skills.

The second variable used in this study is Attitude towards STEM, attitude can be defined in number of ways, attitude is regarded as positive, negative or a neutral feeling about something. Another definition describes attitude as a feeling toward an item or activity that can be good, negative, or neutral (Forgas et al., 2016). In this study attitude is further divided into three sub-domains including cognitive, affective and self-efficacy of teachers' for STEM education. The cognitive aspect includes teachers' comprehension of STEM disciplines' ideas, principles, and methodologies, as well as how to incorporate them into the curriculum. The teachers' interest, enthusiasm, and value for STEM subjects and how to foster them in the trainings is the affective domain .Self-efficacy refers to instructors' confidence in their capacity to successfully teach STEM topics and overcome problems and difficulties. According to the findings of various researchers, instructors' attitudes, views, and knowledge may be seen as their teaching experiences throughout the implementation of integrated STEM disciplines. Teacher trainers' and trainees' STEM knowledge and Attitude towards STEM may be further visualized in the proposed study, as illustrated in figure 1, which concretely displays the conceptual framework of the mutual interactions between each dimension.

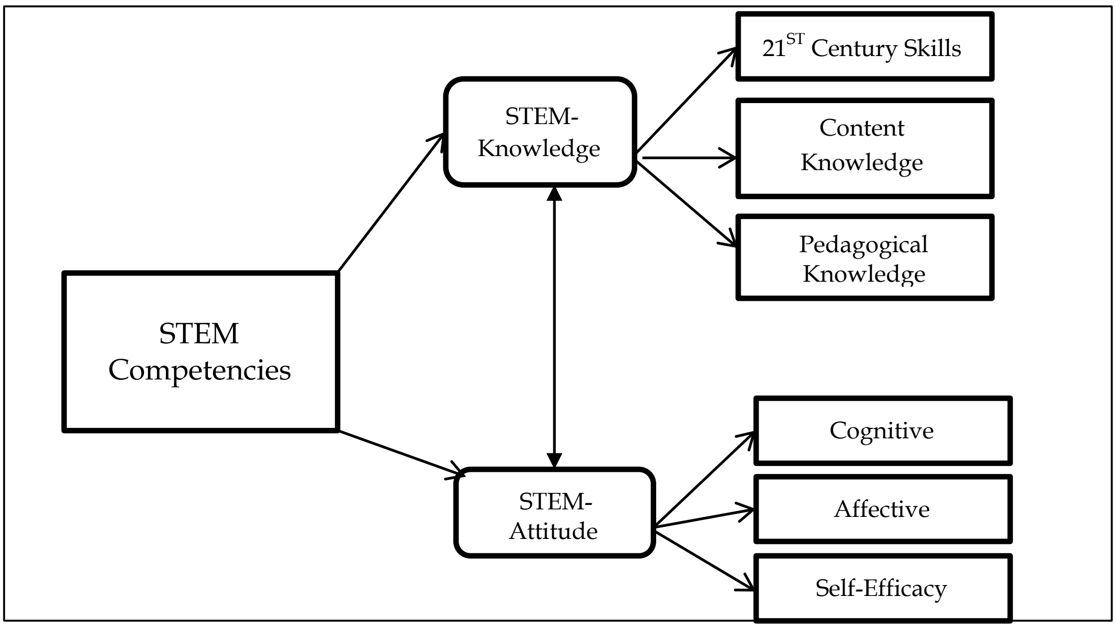

Figure 1. *Conceptual Framework for In-Service Teacher Trainers' and Trainees'*

Literature Review

The Trends in International Mathematics and Sciences Study (TIMSS) 2019 report depicted that the education system of Pakistan is hindered by factors including a lack of conceptual understanding in mathematics subject of grade 4th students as only 27% achieved met the lowest benchmark, which reveals issues in the educational landscape of the country (Memon & Memon, 2021). Moreover, Yildirim and Sahin (2019) noted that the fundamental issues of STEM education required the support of key stakeholders like the Government, teachers and educational leaders as fewer candidates excelled in STEM education along with a lack of understanding of the concepts of STEM disciplines. Teachers, students, and society in general need to work as one if they desire improvement in grades and performance, which depends on precise curriculum, proper teaching methods and assessment standards (Dong et al., 2020).

Pedagogical Content Knowledge (PCK) holds great significance in providing in STEM education in a way that a teacher must have the prerequisite knowledge of the subject, understand the concepts deeply and apply relevant pedagogies to design real world tasks for students. Enhancing PCK skills amongst teachers increased deeper understanding of STEM integration in education and teachers who participated in structured training in PCK improved their instructional practices in STEM with greater student participation in STEM disciplines. Furthermore, incorporating targeted instructions for STEM-specific content and pedagogical knowledge in teacher education programs is necessary for effective STEM integration (Yıldırım & Topalcengiz, 2019). It was reported that teachers had a solid understanding of STEM-PCK but most lack technological scientific integration in STEM disciplines. STEM is a holistic approach which requires to integrate technological expertise with all four disciplines (Ali & Rehmat Shah., 2023).

Attitude is the mental state of a person regarding a particular phenomenon (Wahono & Chang, 2019). Various studies have reported teachers' attitudes regarding STEM education (Thaibut et al., 2018 & Wahono & Chang, 2019). EL-Deghaidy et al. (2017) explored the opinions of teachers regarding the transdisciplinary nature of STEM supporting teachers' self-efficacy for STEM, which would probably involve tying classroom instruction to real-world situations. With rapid globalization calls for advancements in technology in almost every sector. This also emphasises on the need to inculcate 21st century skills among teacher educators. STEM education focuses on inculcating critical thinking and problem solving skills among students, especially in reference to group project work (Ichsan et al., 2023).

Aslam et al. (2022) have emphasized on the need to conduct more researches on the challenges faced in the integration of STEM education especially in rural areas of Pakistan where the availability of STEM teachers, resources and infrastructure amongst many other significant challenges. Traditionally math and science curricula across the globe are not self-sufficient and there is a gap between what is learned in school vs real life scenarios and practical learning (Tytler., 2020). Teachers may enhance their pedagogical practices in reference to real world scenarios and develop link between STEM theoretical concepts and practical solutions. There is a lack of understanding concerning how technology can be incorporated into STEM curricula for teacher's professional development (Ellis et al., 2020). Kiazai et al. (2020) highlighted the need to update teacher education programmes in STEM to address challenges associated with STEM education. According to the literature, there is a growing trend of using technology in the classroom, but there is still little documentation about how educators may be prepared to make use of such tools to improve the learning outcomes of students in low-income backgrounds where they may have little access to such gadgets. Another area that still needs detailed exploration is the follow up of STEM teacher trainings conducted throughout the globe to actually figure out the effectiveness of STEM professional development programs. There is a significant gap in literature regarding teacher trainers and teachers' professional development opportunities of STEM education in the context of Pakistan.

Material and Methods

The research study conducted was based on a quantitative approach. Simple random sampling was used to select 75 teacher trainers and 172 teacher trainees working under federal government setup in Islamabad Pakistan. Two questionnaires were adapted in Pakistani context to analyze the stem knowledge and attitude of teacher trainer and trainees. STEM-Knowledge (PCK-STEM) and STEM attitude (AT-STEM) were adapted from Shidiq & Faikhamta, 2020 and Yildirim& Şahin-Topalcengiz, 2019. Questionnaires were based on a 5-point Likert scale and a pilot study was conducted to establish content validity and reliability respectively. Reliability was assessed using Cronbach's alpha, which was calculated through SPSS Version 21. For Questionnaire-I (STEM-PCK), the Cronbach's alpha was 0.92. Similarly, for Questionnaire-II (Attitude Towards STEM - AT-STEM), the alpha value was 0.82. Furthermore, the questionnaires were validated by experts in STEM disciplines and education.

Results and Discussion

The analysis of teacher trainers' and trainees' knowledge in STEM domains revealed that both groups exhibited a **moderate overall understanding** of STEM education, though notable gaps persisted in specific areas. Among the **75 teacher trainers**, pedagogical knowledge (M = 44.03, SD = 3.98), science knowledge (M = 31.12, SD = 3.47), technology knowledge (M = 30.87, SD = 3.12), engineering knowledge (M = 23.11, SD = 2.49), and 21st-century skills (M = 37.05, SD = 3.02) all fell within a moderate range. However, **mathematics knowledge stood out as comparatively low** (M = 18.88, SD = 2.18), indicating a critical gap in this essential STEM component. The overall STEM knowledge for trainers was also rated as moderate (M = 185.0, SD = 12.28), reflecting a balanced yet non-specialist grasp across domains.

Table 1
STEM-Knowledge Level of Teacher Trainers(n=75)

Dimension	Low	Medium	High	Mean	SD	Interpretation
Pedagogical Knowledge	0–36	37–44	45–54	44.03	3.98	37-44
Science Knowledge	0–28	29–34	35–40	31.12	3.47	29-34
Technology Knowledge	0–27	28–33	34–40	30.87	3.12	28-33
Engineering Knowledge	0–20	21–25	26–30	23.11	2.49	21–25
Mathematics Knowledge	0–20	21–25	26–30	18.88	2.18	21–25
21st Century Skills	0–34	35–39	40–45	37.05	3.02	35-37
STEM Knowledge	0–174	175–199	200–240	185.0	12.28	175–199

Similarly, data from **172 teacher trainees** showed a moderate level of knowledge in pedagogy (M = 44.59, SD = 4.41), science (M = 31.68, SD = 3.73), technology (M = 30.86, SD = 3.32), engineering (M = 22.84, SD = 3.07), and 21st-century skills (M = 37.48, SD = 3.47). As with the trainers, **mathematics knowledge among trainees was also found to be low** (M = 22.62, SD = 3.29), underlining a shared area of concern in STEM preparation. Nonetheless, the **overall STEM knowledge among trainees** was slightly higher than that of the trainers (M = 190.05, SD = 14.14), suggesting that pre-service teachers may be benefiting from more current coursework and pedagogical approaches.

Table 2
STEM-Knowledge Level of Teacher Trainees(n=172)

Dimension	Low	Medium	High	Mean	SD	Interpretation
Pedagogical Knowledge	0–36	37–44	45–54	44.59	4.41	37-44
Science Knowledge	0–28	29–34	35–40	31.68	3.73	29-34
Technology Knowledge	0–27	28–33	34–40	30.86	3.32	28-33
Engineering Knowledge	0–20	21–25	26–30	22.84	3.07	21-25
Mathematics Knowledge	0–20	21–25	26–30	22.62	3.29	21-25
21st Century Skills	0–34	35–39	40–45	37.48	3.47	35-39
STEM Knowledge	0–174	175–199	200–240	190.05	14.14	175-199

When comparing the two groups, **teacher trainees slightly outperformed trainers in pedagogical knowledge** (M = 44.59 vs. M = 44.03) and **21st-century skills** (M = 37.48 vs. M = 37.05), potentially reflecting the emphasis placed on these areas in contemporary teacher education programs. However, both groups shared a common weakness in mathematics, pointing to a need for targeted interventions in this critical area of STEM education

The study further explored teacher trainers' and trainees' attitudes toward STEM education across cognitive, affective, and self-efficacy dimensions. Among **teacher trainers**, the cognitive attitude was found to be **moderate** (M = 34.37), reflecting a reasonable understanding and conceptual acceptance of STEM teaching. Their **affective attitude**, representing emotional interest and enthusiasm, was also moderate (M = 26.72), indicating emotional readiness but lacking high levels of passion or excitement. The **self-efficacy attitude**, associated with confidence in implementing STEM in instructional settings, also fell within the moderate range (M = 18.61). The **overall attitude** of teacher trainers toward STEM education was moderate (M = 79.71), signifying a general openness to STEM approaches but pointing to room for stronger emotional commitment and confidence.

Table 3
STEM-Attitude Level of Teacher Trainers (n=75)

Domain	Low	Medium	High	Mean	SD	Interpretation
Cognitive Attitude	0–30	31–36	37–45	34.37	4.16	31–36
Affective Attitude	0–25	26–30	31–35	26.72	2.69	26–30
Self-Efficacy Attitude	0–17	18–21	22–25	18.61	2.66	18–21
STEM-Attitude	0–74	75–84	85–100	79.71	6.50	75–84

In comparison, **teacher trainees** also exhibited a **moderate cognitive attitude** (M = 35.45), showing that they hold a foundational understanding of STEM principles. However, their **affective attitude** was low (M = 16.5), revealing a limited emotional connection or enthusiasm toward STEM education. Their **self-efficacy** was similarly low (M = 13.5), suggesting a lack of confidence in their capacity to apply STEM methodologies effectively in future classrooms. Despite these weaknesses, the **overall attitude score** of teacher trainees was slightly higher (M = 81.58), still within the moderate category, possibly due to a stronger theoretical understanding.

Table 4
STEM-Attitude Level of Teacher Trainees (n=172)

Domain	Low	Medium	High	Mean	SD	Interpretation
Cognitive Attitude	0–30	31–36	37–45	35.45	3.75	31–36
Affective Attitude	0–18	19–24	25–35	16.5	2.83	0–18
Self-Efficacy Attitude	0–15	16–20	21–25	13.5	2.35	0–15
STEM Attitude	0–74	75–84	85–100	81.58	6.16	75–84

It was revealed that while both groups shared a moderate cognitive orientation toward STEM, **teacher trainers demonstrated stronger affective engagement and self-efficacy** than trainees. Trainers' higher emotional alignment (M = 26.72 vs. 16.5) and confidence (M = 18.61 vs. 13.5) reflected a more balanced and practical attitude profile. Conversely, trainees' attitudes appeared tilted on basic understanding but lacking the emotional drive and self-belief needed for effective STEM instruction. These findings highlighted the need for targeted interventions to **enhance trainees' confidence and emotional investment in STEM**, alongside their theoretical preparation.

Conclusion

The findings of this study revealed an insightful depiction of STEM knowledge and attitudes among teacher trainers and trainees. It was reported that both groups had a moderate understanding of STEM concepts and pedagogical knowledge whereas mathematical knowledge was found to be low in teacher trainers whereas medium in trainees. These persistent weaknesses in mathematics knowledge are concerning and cannot be overlooked. Mathematics forms the backbone of STEM, and the low proficiency in this area undermines the overall effectiveness of STEM education.

Furthermore, it was found that there is a discrepancy between cognitive knowledge and affective domains in teacher trainees. Despite having a reasonable good understanding of STEM topics, teacher trainees demonstrate a lack of emotional connection and confidence in using STEM in educational contexts. This depicted that the existing training programs maybe more theoretical than practical due to which trainess reported lack of motivation. Trainers, on the other hand, exhibited a more balanced attitude but only moderate levels of confidence were reported that indicated their inadequate professional development in this area. These findings highlighted the significance of preparing knowledgeable educators to keep motivated and self-assured in teaching STEM subjects effectively.

Recommendations

A multidimensional approach is necessary to address the identified gaps. First, mathematics in STEM disciplines maybe further emphasized through teacher training programs to substantially update and strengthen STEM curriculum content and inculcate innovative teaching pedagogies to relate mathematics with real life scenarios. Second, to foster genuine interest of teacher trainers and trainees an experiential learning maybe promoted by offering project based activities and collaborations with industrial experts to bridge in theory and practice gap in teachers' professional development options in STEM. Third, building self-efficacy must go beyond classroom instruction. Practical teaching experiences, mentorship programs and reflective practices may be integrated into training to empower trainees with confidence and real-world skills. Fourth, continuous professional development for teacher trainers in STEM disciplines is essential to keep them updated with evolving STEM practices and to enable them to mentor trainees more effectively. Fifth, the use of digital tools may also be embedded in teacher trainings to equip teacher trainers and trainees with self-directed, differentiated and flexible learning experiences that cater to diverse learner needs.

Finally, training programs may embed 21st-century skills seamlessly within STEM content to ensure that educators themselves model critical thinking, creativity, and collaboration. Overall, the study recommended that STEM education reforms must move beyond knowledge attainment to address the emotional and practical dimensions of teaching. Only then can trainers may be truly prepared to inspire and equip the next generation for the demands of a rapidly changing world. Teacher education institutions and policymakers may collaborate to redesign programs that not only deliver content but also cultivate positive attitudes, emotional engagement and teaching readiness in STEM fields as per 21st century standards.

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