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SCIENCE TEACHERS' PERCEPTIONS OF PCK+STEM EDUCATION: A FOUNDATION FOR A TEACHER-TRAINING PROGRAM

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ABSTRACT

This study explored the perceptions and understanding of science teachers in Iligan City regarding Pedagogical Content Knowledge (PCK) and the STEM education approach proposed by Sutaphan and Yuenyong (2019). A mixed-methods design was employed, combining quantitative and qualitative approaches to gain comprehensive insights into teachers' knowledge, familiarity, teaching practices, and training needs. Data were collected from fifteen purposively selected science teachers through semi-structured interviews conducted during a focus group discussion (FGD). The interview guide, developed by the researcher, was validated by six PhD experts in PCK and STEM education, yielding a mean validity score of 3.61, interpreted as "exceeds expectations."

Findings revealed that teachers generally have moderate knowledge of STEM education and high familiarity with PCK, reflecting their professional experience, though they acknowledged a lack of in-depth understanding. Teachers held positive perceptions toward integrating PCK in STEM, recognizing its role in enhancing problem-solving, fostering innovation, and preparing students for future careers. They emphasized that strong PCK enables the design of engaging, relevant, and inquiry-based lessons that connect learning to real-world contexts. However, despite this positive outlook, teachers identified challenges in implementing STEM-based instruction, including limited training and exposure, insufficient time and resources, and difficulties in aligning activities with the existing curriculum. These constraints were seen as barriers to the consistent and meaningful application of PCK-STEM integration in daily practice. Mainly, the study recommends addressing these challenges through curriculum enhancement, adequate resource allocation, and sustained professional development programs focused on PCK-STEM integration. Strengthening teacher collaboration, institutional support, and community partnerships is also vital. Overall, the study underscores the importance of continuous teacher training and reflective practice in promoting effective PCK-STEM integration and fostering student-centered, inquiry-driven learning that develops essential 21st-century skills.

Keyword: PCK; Perceptions; STEM education; Teacher-training

1. Introduction

The primary goal of science education is to nurture scientific literacy among learners, enabling them to become participative and informed citizens capable of making decisions with social, health, and environmental implications (Department of Education, 2016). Despite curriculum reforms, challenges persist in the implementation of science education such as insufficient learning resources, limited teaching strategies, and few learning experiences that develop critical thinking and problem-solving skills (Combalicer, 2016). These issues have prompted scholars to advocate for educational approaches that engage learners in inquiry, exploration, and innovation (Giri & Paily, 2020; Glazewski & Ertmer, 2020).

In response, STEM education has emerged as a transformative framework that integrates Science, Technology, Engineering, and Mathematics to enhance learners' 21st-century skills—critical thinking, collaboration, communication, and creativity. Research suggests that effective STEM instruction encourages inquiry, project-based learning, and real-world applications (Bybee, 2013; English, 2017). However, teachers often struggle with curriculum integration, interdisciplinary coherence, and the pedagogical complexity of implementing STEM instruction (Margot & Kettler, 2019). Moreover, several STEM education models have been proposed to address these challenges. For instance, Bybee's (2013) 5E Instructional Model (Engage, Explore, Explain, Elaborate, Evaluate) promotes inquiry-based learning cycles but focuses primarily on conceptual understanding within science. Breiner et al. (2012) suggested a multidisciplinary STEM framework emphasizing the separate but related teaching of disciplines, while Kelley and Knowles (2016) proposed an integrated STEM framework focusing on engineering design as the unifying component across STEM domains. Although these models encourage active learning and integration, they often emphasize either content mastery or design processes without deeply contextualizing learning within students' social and cultural realities. In contrast, Sutaphan and Yuenyong (2019) developed a 7-Stage STEM Education Model that uniquely connects science learning to societal and environmental issues. The model includes stages of (1) identifying social issues, (2) identifying potential solutions, (3) determining the need for knowledge, (4) decision-making, (5) prototype development, (6) testing and evaluation, and (7) socialization of solutions. This framework enhances students' problem-solving, creativity, and teamwork while simultaneously enriching teachers' PCK through experiential learning design. It highlights the interdependence of STEM and PCK in promoting authentic, meaningful learning. In addition, Pedagogical Content Knowledge (PCK), as introduced by Shulman (1986), represents the teacher's ability to transform subject content into forms comprehensible to learners through appropriate strategies, representations, and assessments. Within STEM education, PCK plays a vital role in translating abstract concepts into meaningful, contextual learning experiences. However, research shows that many science teachers struggle to make their PCK explicit, leading to challenges in adapting instruction to student needs (Rozenszajn & Yarden, 2014; Demirdöğen & Uzuntiryaki-Kondakçı, 2016; Taber, 2014). This gap underscores the need for structured support to move teachers from implicit to reflective and explicit PCK practice.

Despite these promising frameworks, STEM implementation remains limited, particularly in developing contexts. Research identifies teacher readiness, curriculum alignment, and interdisciplinary integration as persistent challenges (Lee, 2019). In STEM contexts, teaching effectiveness depends largely on teachers' PCK their ability to convert disciplinary knowledge into accessible and engaging learning experiences (Mientus, 2022). This relationship between STEM and PCK represents a critical gap, as many educators remain untrained in integrating these frameworks effectively. Meanwhile, in the Philippine context, studies show that while STEM education is gaining recognition, teachers' perceptions and PCK development remain underexplored (Constantino & Antonio, 2025). National assessments such as PISA (OECD, 2015) and findings from EDCOM II (2023) have revealed systemic issues including insufficient teacher training, lack of teaching materials, and inadequate professional support. These challenges contribute to the country's low performance in science and mathematics and highlight the urgency of addressing teachers' pedagogical and content knowledge development. Moreover, Mafugu et al. (2024) found that teachers often rely on traditional, teacher-centered methods that limit critical thinking, further demonstrating the need for innovative PCK-STEM integration.

Notably, teacher professional knowledge, especially PCK, has the greatest impact on improving student performance and educational outcomes (Knight, 2012). However, studies by Nadelson et al. (2013) and Stohlmann et al. (2012) reveal that many teachers still lack pedagogical knowledge and efficacy in STEM instruction, emphasizing the need for sustained professional development programs (Yoon & Klopfer, 2006). The Institute for the Promotion of Teaching Science and Technology (IPST, 2002) also stresses that teacher preparation and continuous training are key determinants of educational success.

Given these considerations, this study aims to explore science teachers' perceptions, understanding, and application of PCK and STEM education approaches. By identifying teachers' challenges, instructional practices, and professional development needs, the research seeks to provide insights into how PCK-STEM integration can enhance instructional quality and learning outcomes in the Philippine setting. Strengthening teacher capacity through PCK-STEM-based training, mentoring, and classroom support is essential to bridging the gap between policy goals and classroom realities, thereby advancing science education reform.

2. Research objective

The general objective of this study is to assess the perception science teachers in adopting Pedagogical Content Knowledge (PCK) and STEM education teaching approach in their classroom. Specifically, it aims to:

1. Assess the level of science teachers' familiarity with the concepts and principles of Pedagogical Content Knowledge (PCK) and STEM education approaches.
2. Identify teachers' current teaching practices in the classroom.
3. Determine the challenges encountered by science teachers in integrating PCK and STEM approaches into their instruction.
4. Explore the perceived professional development needs of science teachers for effective implementation of PCK and STEM-based teaching, including their training and support requirements.

3. Theoretical framework

This study is firmly rooted in a multi-theoretical framework that relates Pedagogical Content Knowledge (PCK) and STEM education as a teaching approach. These frameworks provide a relevant assessment in interpreting how teachers content knowledge, pedagogical skills, and contextual knowledge interact to shape curriculum design and student outcomes.

Sutaphan's and Yuenyong, (2019) 7-Stage STEM Education Model provides a structured framework for designing integrated STEM lessons. It guides learners from identifying real-world problems to applying scientific and technological knowledge in authentic contexts through inquiry, creativity, and problem-solving. Aligned with Shulman's Pedagogical Content Knowledge (PCK), the model helps teachers transform disciplinary content into meaningful, contextualized learning experiences by integrating content, pedagogy, and context. Unlike other frameworks such as Bybee's, (2013) 5E Model, which focuses on inquiry-based learning, or Kelley and Knowles, (2016) framework, which centers on engineering design, Yuenyong's model uniquely incorporates socio-scientific issues and local cultural contexts. It promotes community-based problem solving, social responsibility, and reflective teaching making it a holistic and culturally responsive approach to STEM education.

Shulman's concept of Pedagogical Content Knowledge (PCK). Introduced by Lee S. Shulman (1986), PCK bridges the gap between content knowledge (what teachers know) and pedagogical knowledge (how they teach). Mainly, it serves as a central theoretical foundation in understanding the nature of teacher expertise and instructional effectiveness. It further emphasizes that effective teaching goes beyond mastery of subject matter—it requires the ability to transform complex disciplinary concepts into forms that are comprehensible to learners. This includes selecting appropriate representations, analogies, and examples, anticipating student misconceptions, and employing strategies that promote conceptual understanding. Within the context of STEM education, PCK offers a perspective for analyzing how teachers integrate scientific principles, technological tools, engineering design, and mathematical reasoning into cohesive, inquiry-based learning experiences.

Technological Pedagogical Content Knowledge (TPACK). The TPACK framework builds on Shulman's construct of Pedagogical Content Knowledge (PCK) to include technology knowledge as situated within content and pedagogical knowledge. It introduces the relationships and the complexities between all three basic components of knowledge (technology, pedagogy, and content) (Koehler & Mishra, 2008; Mishra & Koehler, 2006). Overall, it is a more integrated whole for the three kinds of knowledge addressed: technology, pedagogy, and content (Thompson & Mishra, 2007–2008). Thus, the integration of PCK and STEM is anchored in the belief that applying a dynamic and technology-enhanced approach, as emphasized in the TPACK framework, can lead to greater student engagement to foster deeper learning experiences.

Situated Learning Theory. This was first proposed and described by Jean Lave and Etienne Wenger (1991) as a theoretical description of learning through participation in a community of practice in which they viewed learning as a social process, occurring within authentic contexts which also states that learning should not be merely viewed as transmission of knowledge but as an embedded and active process. A situated learning space is one where learning and its application takes place in the same location. They believed that students were likely to learn more by actively participating in their learning domain as opposed to listening to lecturers in classrooms. Situated learning is a mechanism by creating meaning from the real-life activities where learning occurs. The community implies a group of people willing to work together and prepared to support each other's coming to know (Lave & Wenger (1991) in which align to STEM in relation to collaborative and experiential learning of the students.

Transformative Learning Theory. This theory explains how adult learners make sense or meaning of their experiences, how social and other structures influence the way they construe that experience, and how the dynamics involved in modifying meanings undergo changes when learners find them to be dysfunctional (Mezirow, 1991). This is where individuals change their perspectives through critical reflection and it further focused on individual transformation but it too emphasizes rational and non-coercive dialogue as a means to make a change for the better. Besides, STEM Education encourages teachers to transform their teaching practices through reflection and professional development, fostering a shift toward innovative, student-centered STEM education.

Constructivist Learning Theory. Jean Piaget's (1896- 1980) work on educational psychology influenced the initial idea of constructivism. It focuses on how humans create meaning when their experiences and ideas interact. The fundamental tenet of constructivism is that students learn through engagement rather than observation. While Piaget's cognitive theory is individualistic and describes how children acquire cognitive skills as they grow, Lev Vygotsky (1896–1934) emphasized the social context of learning. Vygotsky subsequently developed social constructivism that emphasizes "the significance of sociocultural learning; how learners internalize interactions with adults, more capable peers, and cognitive tools to form mental constructs via the zone of proximal development. Which is suitable to Sutaphan and Yuenyong, (2019) emphasizes inquiry-based and student-centered learning, that are grounded in constructivist principles. Teachers with strong PCK guide students to explore STEM concepts through hands-on, experiential learning.

Inquiry-Based Learning (IBL). The American educator and philosopher John Dewey (1859-1952), was largely responsible for promoting 'learning by doing' (Dewey, 1933) which emphasizes student exploration and questioning, encouraging learners to investigate and 10 discover solutions. Influenced by Dewey, inquiry-based learning was adopted by many school teachers in the 1970s and began to appear about the same time in tertiary institutions. Bell et al., (2005) use the phrase, 'active learning process', to refer to the nature of inquiry where students are expected to answer a research question using data analysis and information exchange. With this, STEM Education approach aligns closely with IBL, focusing on engaging students in problem-solving and innovation through inquiry-led STEM lessons.

Mainly, the integration of Pedagogical Content Knowledge (PCK) and STEM Education creates a dynamic framework that empowers teachers to transform disciplinary content into meaningful, real-world learning experiences. Grounded in Shulman's (1986) concept of PCK, which bridges what teachers know and how they teach, and aligned with Yuenyong and Sutaphan's (2019) 7-Stage STEM Education Model, this integration guides teachers through a structured process of engaging students in authentic problem-solving, scientific inquiry, and engineering design. The inclusion of Technological Pedagogical Content Knowledge (TPACK) further enhances this model by embedding technology into pedagogy and content to promote active, technology-rich learning. Supported by Constructivist, Situated, Transformative, and Inquiry-Based Learning Theories, the PCK+STEM framework emphasizes that effective teaching occurs when students construct knowledge through collaboration, reflection, and authentic engagement. Altogether, PCK+STEM fosters a student-centered, inquiry-driven, and integrative approach that mirrors real-world scientific and engineering practices while enabling teachers to enact their pedagogical expertise in guiding learners toward deeper understanding and innovation.

4. Research methodology

4.1 Research Design

This study utilized a mixed-methods research design, incorporating both quantitative and qualitative approaches to provide a comprehensive understanding of the topic. The quantitative component involved the collection of numerical data, which were analyzed and presented through chart and tables to illustrate trends, distributions, and levels of teachers' familiarity and understanding of PCK and STEM education. The qualitative component employed thematic analysis of interview responses and open-ended survey questions, allowing the researchers to identify patterns, themes, and deeper insights into how teachers conceptualize, implement, and value the integration of PCK and STEM in classroom instruction. Combining these approaches enabled the study to triangulate findings, offering both breadth and depth of understanding.

4.2 Respondents and Research Locale

The respondents of the study were fifteen (15) purposively selected science teachers from both junior and senior high schools in the Division of Iligan City, regardless of whether they possess prior knowledge or experience in Pedagogical Content Knowledge (PCK) and the STEM education approach. Purposive sampling was employed to identify participants who could provide rich and relevant insights regarding the integration of Pedagogical Content Knowledge (PCK) and STEM education in classroom practice. As defined by Fraenkel, Wallen, and Hyun (2012), purposive sampling differs from convenience sampling in that researchers do not simply select whoever is available; rather, they intentionally choose participants based on specific criteria and informed judgment to ensure that the data collected meaningfully address the research objectives. The inclusion criteria for the respondents were as follows: (1) they must be currently teaching Biology either in junior or senior high school; (2) they must have at least two (2) years of teaching experience in the field of science; and (3) they may or may not have prior knowledge or formal training in STEM education or Pedagogical Content Knowledge (PCK). These criteria ensured that participants possessed sufficient classroom experience to reflect on their instructional practices while allowing for diverse perspectives on the understanding and application of PCK and STEM teaching approaches. Moreover, six (6) validators expert in PCK and STEM evaluated the questionnaire to ensure its clarity, relevance, and overall validity.

4.3 Research Instruments

4.3.1 Validation of the research instrument

To gather the necessary data, the study utilized a researcher-made questionnaire composed of twenty (20) items consisting of five parts: (I) demographic profile of respondents, (II) knowledge of STEM education, (III) teaching practices, (IV) perceived challenges and available resources, and (V) Pedagogical Content Knowledge (PCK) and (VI) professional development needs. The six-part structure of the questionnaire was designed to comprehensively capture the multifaceted nature of teachers' knowledge, practices, and professional needs in relation to PCK and STEM education. The inclusion of the demographic profile provided contextual background necessary for interpreting teachers' experiences (Fraenkel, Wallen, & Hyun, 2012). The section on knowledge of STEM education aimed to assess teachers' conceptual and theoretical understanding of STEM principles, aligning with Bybee's (2013) argument that teachers' comprehension of STEM philosophy is foundational to effective implementation. The teaching practices section sought to determine how teachers integrate interdisciplinary and inquiry-based strategies in the classroom, consistent with Kelley and Knowles (2016) who emphasized practice-based evidence in understanding STEM pedagogy. Exploring perceived challenges and available resources was crucial to identifying systemic and contextual barriers that affect instructional delivery, as supported by Margot and Kettler (2019) who noted that teachers' perceptions of support and resources significantly influence STEM enactment. The inclusion of a Pedagogical Content Knowledge (PCK) section was guided by Shulman's (1986) framework, which highlights the intersection of content, pedagogy, and context as the core of effective teaching.

In addition, the professional development needs section was incorporated to align with Guskey (2002), who emphasized that understanding teachers' training needs is essential for designing relevant professional learning programs that foster growth and innovation in instructional practices. Collectively, these sections ensured that the instrument captured both cognitive and contextual dimensions of PCK-STEM integration, allowing for a comprehensive understanding of teachers' perceptions and experiences. Meanwhile, the questionnaire underwent validation by six Ph.D evaluators who has knowledge and expertise of PCK and STEM Education to carefully assessed its quality and effectiveness based on several criteria. The validation process followed the recommendation of Creswell and Creswell (2018) and Fraenkel, Wallen, and Hyun (2012) that expert review is a critical step in developing data collection tools to establish content validity and alignment with research objectives. The parameters include: clarity and organization, wordiness, consistency and parallelism of stems and options, and the appropriateness of each item in relation to the intended learning targets. The 4-point scale used was: 1.00–1.75 = Not Acceptable (major modifications needed), 1.76–2.50 = Below Expectations (some modifications needed), 2.51–3.25 = Meets Expectations (minor improvements possible), and 3.26–4.00 = Exceeds Expectations (no modifications needed).

Table 1. Mean Evaluation Scores of Validators Across Parameters

Parameters	Validator 1	Validator 2	Validator 3	Validator 4	Validator 5	Validator 6	Mean
Clarity and Organization	3.5	3.5	3.5	3.6	3.4	3.5	3.50
Wordiness	3.4	3.7	3.6	3.7	3.4	3.8	3.60
Consistency and Parallelism of Stem and Options	3.5	3.6	3.5	3.6	3.5	3.5	3.53
Appropriateness of Item to Learning Target	3.9	3.7	3.9	3.8	3.7	3.8	3.80
Grand mean							3.61

After thorough evaluation, the instrument obtained a grand mean score of 3.61, which signifies that the questionnaire meets the evaluators' expectations in terms of content quality, structure, and relevance with minor changes. However, clarity and organization obtained the lowest mean score, indicating that this aspect needs an improvement to enhance coherence and structure while, appropriateness to the learning target received the highest mean score, suggesting that the items were highly aligned with the intended learning objectives. This result indicates that the instrument is acceptable and suitable for use in gathering reliable and valid data. As noted by DeVellis (2017), expert evaluation and iterative refinement are essential steps in establishing the face and content validity of research instruments to ensure the accuracy and meaningfulness of data obtained from respondents.

4.4 Data Gathering and Analysis

Questionnaires were distributed to science teachers, and informed consent was included to ensure that participation was voluntary and aligned with established ethical research standards. Participants were informed about the study's purpose, procedures, and confidentiality measures prior to their participation. To maintain anonymity, a coding system was employed wherein each participant was assigned an alphanumeric code (e.g., T1, T2, T3), ensuring that no identifying information appeared in the dataset or subsequent reports. Following the survey, semi-structured interviews were conducted during Focus Group Discussions (FGDs) to gather more in-depth insights into teachers' perceptions, experiences, and professional needs regarding PCK and STEM education. The interview protocol was carefully developed based on the study's research questions and reviewed by experts in qualitative research and STEM education to ensure clarity, relevance, and alignment with the research objectives. Each FGD session consisted of five participants and lasted approximately 60–90 minutes. A moderator facilitated the discussion, guided by an interview guide composed of open-ended questions that encouraged participants to share their thoughts freely while ensuring that all core topics such as understanding of STEM education, integration of PCK, challenges, and training needs were addressed. Follow-up questions and probes were used as necessary to elicit detailed responses and clarify meanings.

Prior to data collection, a pilot interview was conducted with five (5) non-participant science teachers to test the clarity and appropriateness of the interview questions. Minor adjustments were made to ensure that the wording and sequence of questions promoted natural dialogue and rich data generation. During the actual interviews, participants were reminded of their right to withdraw at any point without penalty. With permission, all interviews were audio-recorded to ensure accuracy, while field notes were taken to capture non-verbal cues and contextual details. After data collection, the recorded interviews were transcribed verbatim and reviewed by the researcher for accuracy. The transcriptions were then subjected to thematic analysis following Braun and Clarke's (2006) six-phase framework: (1) familiarization with the data, (2) generation of initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report. Thematic analysis was chosen for its flexibility and suitability in identifying recurring patterns, meanings, and shared experiences among participants. The process ensured that emerging themes accurately represented teachers perceptions related to PCK and STEM integration, thereby addressing the study's objectives in a rigorous and systematic manner.

5. Research findings and Discussions

The responses gathered from Junior and Senior High School teachers regarding their expectations and needs for professional development in Pedagogical Content Knowledge (PCK) and STEM education were analyzed using thematic analysis to identify, organize, and interpret recurring patterns and themes within the data that captured their shared perceptions and insights.

5.1 Knowledge and understanding of STEM Education as a teaching approach

This section presents teachers' knowledge of STEM education as a teaching approach in the classroom, highlighting their varying levels of understanding, awareness, and application. It explores how teachers conceptualize STEM education in terms of its principles, integration across disciplines, and relevance to real-world contexts. Furthermore, it examines the extent to which teachers are able to translate their knowledge into effective classroom practices that promote inquiry, problem-solving, and collaboration among students.

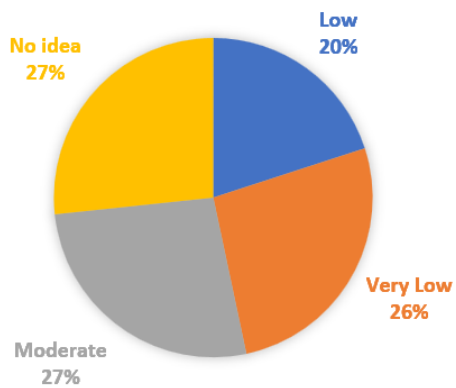

Figure 1. Teachers Familiarity with STEM as a Teaching Approach in Education

Figure 1 presents the teachers' familiarity and understanding of the STEM education approach. The graph reveals that most respondents rated their familiarity as low to moderate, while a smaller number rated it as very low comprising 26%, and 27% of the respondents indicated that they had no idea about STEM. Also, 27% stated they had moderate familiarity and 20% as Low. This finding suggests that while teachers are somewhat aware of STEM, their understanding remains limited and inconsistent across respondents. Furthermore, these results, showed three main categories: STEM as a General Concept, STEM as an Academic Strand or Curriculum Track, and STEM as an Unapplied Pedagogical Concept. Under the first category, *STEM as a General Concept*, teachers expressed only surface-level awareness, as reflected in statements such as, *"I have heard of STEM but only know it in general terms"* (T8) and *"I know STEM is important, but I don't fully understand how to integrate it into classroom practice"* (T5). This implies that teachers recognize the value of STEM but have not yet developed a strong pedagogical understanding. The second category, *STEM as an Academic Strand or Curriculum Track*, captures a widespread misconception where teachers identify STEM merely as a senior high school strand under DepEd, rather than an instructional framework.

Moreover, as stated by some teachers, *"STEM is one of the senior high school strands in DepEd"* (T14) and *"We mostly know STEM as a curriculum track for students, not as a teaching approach"* (T6). This interpretation reveals that teachers often view STEM as a curricular classification rather than a teaching approach that promotes integration across science, technology, engineering, and mathematics disciplines. Then, the third category, *STEM as an Unapplied Pedagogical Concept*, emphasizes the teachers' lack of training and exposure to STEM-based instructional strategies. Several participants admitted, *"We were not trained much on STEM teaching strategies"* (T11) and *"We need workshops to fully understand STEM as an instructional approach"* (T12). These statements highlight the gap between awareness and practice, suggesting that teachers are interested in STEM but lack the necessary competencies to implement it effectively.

These findings are consistent with previous studies. For instance, Bybee (2013) emphasized that many teachers understand STEM only as a subject area rather than an integrative teaching approach that fosters problem-solving and innovation. Similarly, Roehrig, Moore, Wang, and Park (2012) found that teachers often struggle to conceptualize STEM beyond their disciplinary boundaries, limiting their ability to apply integrated teaching strategies. Moreover, Yuenyong and Narjaikaew (2009) noted that the implementation of STEM education in developing contexts is hindered by teachers' insufficient training and conceptual understanding of STEM pedagogy. Overall, the findings indicate that teachers have limited understanding of STEM as a pedagogical approach, with four respondents having no idea at all. These results align with previous research and underscore the urgent need for professional development programs that focus on building teachers' conceptual and practical understanding of STEM integration in classroom instruction.

Table 2. Previous training in STEM education

Quotes (from Teachers)	Code	Category	Theme
"Seminars and workshops helped me understand the basics of STEM and improve my teaching strategies." (T1, T3, T6)	Exposure to STEM fundamentals and pedagogy	Seminars and Workshops	Participation in Formal STEM Training Enhanced Pedagogical Skills
"STEM training allowed me to connect concepts with real classroom practice and apply integration strategies." (T4, T5, T7)	Practical application and classroom integration	Hands-on/Practical Training Sessions	Practical Application of STEM Integration from Training
"I have not undergone formal STEM training, but I am willing to attend workshops to improve my teaching." (T9, T11, T14)	Lack of formal training but willingness to learn	Absence of Training but Interest in Learning	Interest and Willingness to Engage in Future Training
"I only know STEM as a strand, but I am open and eager to attend professional development." (T12, T15)	Limited perception but interest in training	Awareness from College or Curriculum Exposure	Enthusiasm and Curiosity Toward STEM Despite Limited Training
"Even without formal training, I am enthusiastic and curious to apply STEM if given the chance." (T10, T13)	Curiosity and eagerness despite lack of training	Self-Motivated Exploration of STEM Concepts	

Some teachers reported attending STEM-related seminars and workshops, which helped them gain exposure to STEM pedagogy, apply interdisciplinary strategies, and develop inquiry-based skills (T1, T3, T6, T8). This reflects Bybee's (2013) view that professional learning enhances teachers' ability to connect STEM concepts to practice, and Kelley and Knowles (2016) emphasize that structured training supports effective integration. Others admitted they had no formal training, often understanding STEM only as a curriculum strand (T9, T11, T12, T14, T15).

However, they expressed strong interest in future training, consistent with Margot and Kettler's (2019) finding that teachers without training show willingness to engage in professional development. Meanwhile, teachers noted that prior training allowed them to apply STEM beyond theory, boosting classroom confidence T2, T4, T5, T7), which supports English's (2016) claim that STEM training encourages real-world applications. Similarly, T10 and T13 showed enthusiasm despite lacking training, aligning with El-Deghaidy and Mansour's (2015) assertion that teacher motivation is key to adopting STEM approaches. Overall, the findings highlight that while some teachers gained practical skills from training, others lacked exposure but showed eagerness to learn—underscoring the need for sustained STEM professional development.

Table 3. Incorporating STEM Activities or Lessons in their Teaching Practice

Quotes (from Teachers)	Code	Category	Theme
"I integrate real-life problem-solving through math, inquiry projects, engineering challenges, and data-driven activities." (T1, T5, T9, T12, T14)	Real-life application, inquiry, engineering, and data-based learning	STEM-Based Instructional Strategies	Active STEM Integration in Teaching Practice
"I haven't integrated STEM due to lack of training, confidence, and resources, relying on traditional methods." (T3, T6, T8, T10, T13)	Barriers: lack of skills, resources, and reliance on traditional teaching	Challenges and Constraints in STEM Implementation	Limited STEM Integration Due to Constraints
"I believe STEM fosters engagement, creativity, and collaboration, and I want to try hands-on activities." (T2, T4, T7, T11, T15)	Recognizing STEM's benefits and openness to new approaches	Positive Perceptions and Motivation Toward STEM	Interest and Openness to Future STEM Integration

The findings show that some teachers have actively applied STEM by integrating real-life problem-solving, inquiry-based approaches, engineering challenges, and data-driven activities This reflects English's (2016) view that effective STEM practice fosters inquiry, collaboration, and creativity through interdisciplinary learning. In contrast, others admitted limited STEM integration due to lack of training, confidence, and resources which aligns with Margot and Kettler's (2019) finding that barriers often hinder teachers from implementing STEM despite awareness. Meanwhile, several teachers expressed openness and enthusiasm toward STEM, seeing it as a way to promote engagement, creativity, and hands-on learning. This supports El-Deghaidy and Mansour's (2015) argument that teacher motivation and willingness play a crucial role in adopting STEM pedagogy. Overall, the responses highlight both existing practices and challenges, underscoring the importance of professional development to expand STEM integration in classrooms.

Table 4. Confidence in teaching STEM subjects

Quotes (from Teachers)	Code	Category	Theme
"I feel confident in teaching STEM because of my prior training and experience." (T4, T8)	Confidence from training and experience	Confidence Rooted in Experience and Training	High Confidence in Teaching STEM
"I am confident because I've practiced STEM in my lessons." (T9)	Confidence from practice		
"I am somewhat confident, but I need more practice and exposure." (T1)	Partial confidence with need for practice and exposure	Developing Confidence with Limited Exposure	Moderate Confidence with Need for Development
"I am fairly confident but still need professional development and training." (T5, T10, T15)	Confidence with desire for training		

Quotes (from Teachers)	Code	Category	Theme
"I am somewhat confident but unsure about integrating multiple disciplines." (T11, T13)	Struggle with cross-disciplinary integration		
"I am not confident because I have no STEM training and limited understanding." (T2, T7)	Lack of training and understanding	Insufficient Knowledge and Training	Low Confidence Due to Lack of Training
"I lack confidence because I don't know how to apply STEM in teaching." (T3, T12)	Uncertainty in application		
"I am not confident at all without proper guidance and support." (T6, T14)	Need for guidance, support, and exposure		

Out of the fifteen teachers, only three expressed high confidence in teaching STEM, which was attributed to prior training, familiarity, and classroom practice an observation consistent with Hurley et al. (2023) and Zhou et al. (2023), who emphasized that professional development and hands-on experiences significantly enhance teachers' self-efficacy. Four teachers reported moderate confidence but highlighted the need for more practice, professional development, and support in integrating multiple disciplines, echoing the findings of Rehman et al. (2025) and Margot and Kettler (2019), who noted that while teachers value STEM, they often struggle with pedagogical challenges and curriculum integration.

Meanwhile, six teachers admitted low confidence, citing lack of training, uncertainty in application, and absence of proper guidance, which aligns with Papagiannopoulou (2024) and Roberts (2024), who stressed that insufficient training and lack of clarity in STEM pedagogy undermine teacher confidence. Overall, these findings reinforce the view that while a small number of teachers are highly confident, the majority require structured guidance, sustained training, and professional support to effectively implement STEM education.

Table 5. Teachers View on STEM Education Characteristic

Quotes (from Teachers)	Code	Category	Theme
"STEM helps in solving real-life problems through integration of different disciplines." (T1, T2)	Real-world problem-solving	Integration of Knowledge and Real-World Relevance	Practical Application of STEM
"STEM allows students to apply what they learn in addressing practical issues." (T3, T4)	Application of knowledge to real-world contexts		
"STEM connects learning to everyday life and increases student engagement." (T6, T7)	Relevance to daily life and student motivation	Student Engagement and Relevance of Learning	Relevance and Engagement in STEM
"STEM provides meaningful experiences that make students more interested in learning." (T8, T9, T15)	Enhancing interest and classroom engagement		
"STEM fosters inquiry and collaboration in solving problems." (T11, T12)	Promoting inquiry and teamwork	Inquiry-Based and Collaborative Learning	Fostering Inquiry and Innovation through STEM
"STEM encourages creativity and innovation across different fields." (T13, T14)	Creativity and interdisciplinary innovation		

Teachers described STEM as an interdisciplinary approach that addresses real-world challenges, enhances engagement, and fosters creativity. They also emphasized STEM's role in solving practical problems, aligning with Bybee's (2013) view that STEM education equips learners with skills for authentic problem-solving. Others, highlighted its relevance in connecting lessons to everyday life and boosting student motivation, which supports Margot and Kettler's (2019) finding that STEM enhances meaningful engagement. Meanwhile, several teachers underscored STEM's capacity to promote inquiry, collaboration, and innovation, consistent with Kelley and Knowles' (2016) argument that integrated STEM fosters creativity and interdisciplinary learning.

5.2 Teaching Practices

This section presents teachers' practices inside their classrooms in implementing various instructional strategies when discussing science lessons to facilitate student learning. It delves into how teachers design and deliver lessons that engage students through inquiry-based, hands-on, and collaborative activities aligned with STEM education principles. Moreover, it highlights the approaches teachers use to address diverse learning needs, promote critical thinking, and connect scientific concepts to real-life situations, thereby enhancing students' understanding and appreciation of science.

Table 6. Approached in teaching science

Quotes (from Teachers)	Code	Category	Theme
"I usually rely on lectures to explain science concepts." (T1, T2)	Teacher-centered, lecture-based methods	Traditional Instructional Practices	Traditional Lecture-Focused Teaching
"I design hands-on activities for students to learn by doing." (T3, T4)	Activity-driven, experiential strategies	Experiential and Student-Centered Strategies	Hands-On and Collaborative Learning
"I let students work together on collaborative science tasks." (T5, T14)	Group work and peer collaboration		
"I combine lectures with interactive activities to balance theory and practice." (T6, T7, T8, T13)	Blending teacher input with student-centered tasks	Blended or Mixed Teaching Methods	Hybrid Teaching Approach
"I encourage students to explore, ask questions, and discover concepts on their own." (T9, T10)	Emphasis on inquiry, exploration, and discovery	Inquiry-Oriented Instructional Strategies	Inquiry-Based Teaching
"I use inquiry-based strategies to guide students in investigations." (T11, T12, T15)			

Teachers demonstrated diverse approaches to science teaching. Some teachers relied on lecture-focused strategies, reflecting traditional teacher-centered instruction (Goodrum et al., 2001). Others emphasized activity-driven, hands-on, and collaborative learning, aligning with Kolb's (2014) experiential learning theory. Several teachers also adopted hybrid methods that blended lectures with interactive tasks, which supports Vygotsky's (1978) idea of combining guidance with active participation. However, others preferred inquiry-based teaching that fosters student exploration and discovery, consistent with Llewellyn's (2013) argument that inquiry enhances critical thinking and scientific literacy.

Table 7. Teaching strategies in STEM in lesson

Quotes (from Teachers)	Code	Category	Theme
"I use project-based learning to let students solve problems across subjects." (T1, T2)	Project-based, hands-on, problem-solving approaches	Interdisciplinary and Experiential Learning Approaches	Active STEM Integration through Projects and Experiments
"I conduct hands-on experiments to integrate science and math concepts." (T3)			
"I connect lessons to real-life applications to make learning meaningful." (T6, T7)	Real-life relevance, collaboration, inquiry	Authentic and Contextualized Learning	STEM Integration through Real-Life and Inquiry-Based Learning
"I encourage collaborative group activities and inquiry-based investigations." (T8, T9)			
"I apply simple demonstrations and class discussions with some cross-curricular links." (T11, T12)	Basic or partial STEM integration; expressed need for support	Foundational STEM Practices with Professional Development Needs	Emerging STEM Integration with Training Needs
"I try basic integration but still need more training and support." (T13, T14, T15)			

Teachers employed varied strategies in integrating STEM. Some used project-based learning, problem-solving, and hands-on experiments, reflecting Bybee's (2013) argument that STEM promotes authentic problem-solving through active engagement. Others mainly emphasized real-life applications, collaboration, and inquiry-based tasks, aligning with Kolodner et al. (2003), who highlight the role of inquiry and teamwork in fostering critical thinking. Moreover, several teachers applied only basic integration such as demonstrations and discussions, noting the need for more training and support, consistent with Margot and Kettler's (2019) finding that teachers often face challenges in STEM implementation without adequate professional development.

Table 8. Assessing Students' STEM Understanding and Real-World Application

Quotes (from Teachers)	Code	Category	Theme
"I use project outputs and performance tasks to see how students apply concepts." (T1, T2, T5)	Assessing through projects, tasks, and experiments	Application-Oriented and Performance-Based Evaluation	Performance- and Application-Based Assessment
"I conduct hands-on experiments as part of assessment." (T3, T10)			
"I rely on written tests and student presentations to check comprehension." (T6, T7)	Written, oral, and collaborative assessments	Traditional and Interactive Assessment Techniques	Assessment through Written and Interactive Tasks
"I use group activities and class discussions for evaluation." (T4, T8, T9)			

Quotes (from Teachers)	Code	Category	Theme
"I present real-life problem scenarios to assess student understanding." (T11, T12)	Practical, inquiry-driven, and reflective assessments	Contextual and Inquiry-Based Evaluation	Inquiry- and Real-Life Context Assessment
"I use inquiry-based activities and reflective questioning to measure application." (T13, T14, T15)			

Teachers used varied strategies to assess STEM learning. Some relied on project outputs, performance tasks, and experiments, which aligns with Bybee's (2013) view that authentic tasks measure real application of STEM skills. Others used written tests, presentations, and group discussions, reflecting Black and Wiliam's (2009) assertion that diverse assessments support both comprehension and problem-solving. Likewise, several teachers applied real-life scenarios, inquiry-based tasks, and reflective questioning, consistent with Pellegrino (2014), who emphasized that meaningful assessment should capture students' ability to apply knowledge in practical contexts.

5.3 Perceived Challenges in the future implementation of PCK and STEM Education

This section showcases the teachers' perceived challenges and available resources related to the future implementation of the PCK and STEM teaching approach. It highlights several factors that may either hinder or support its effective integration into classroom instruction. The discussion explores issues such as limited access to instructional materials, inadequate training opportunities, time constraints, and curriculum alignment, which may affect teachers' ability to fully implement PCK and STEM-based strategies. Conversely, it also identifies existing supports such as administrative encouragement, peer collaboration, and access to technology and learning materials that can facilitate successful integration. By examining these challenges and resources, this section provides valuable insights into the conditions necessary for promoting sustainable and effective PCK- and STEM-oriented teaching practices.

Table 9. Anticipated Challenges in implementing STEM Instruction

Quotes (from Teachers)	Code	Category	Theme
"I am not very familiar with STEM concepts, so it is hard to teach them effectively." (T1, T2, T10)	Limited familiarity, skills gaps, difficulty engaging learners	Knowledge and Pedagogical Limitations	Instructional Challenges in STEM Teaching
"Maybe the struggle to fully engage students in STEM-based lessons." (T3, T12)			
"Perhaps lack of sufficient teaching materials for STEM activities." (T6, T7)	Shortage of resources and equipment	Resource Availability and Material Constraints	Resource-Related Challenges in STEM
"There is not enough equipment to carry out experiments." (T5, T8, T9)			
"We don't have enough time for lesson planning." (T11, T13)	Time constraints, curriculum rigidity, lack of admin support	Institutional and Structural Limitations	Institutional and Structural Challenges
"The curriculum and schedule limit how I can apply STEM." (T4, T15)			

Teachers identified three main challenges in teaching STEM. Some reported instructional issues such as limited familiarity and difficulty engaging students, reflecting Bybee's (2013) argument that effective STEM requires strong teacher competence. While others also highlighted lack of materials and equipment, consistent with Margot and Kettler's (2019) finding that resource shortages hinder STEM integration. Additionally, there are several teachers pointed to institutional barriers like time constraints and curriculum rigidity, aligning with Stohlmann, Moore, and Roehrig's (2012), view that systemic support is essential for successful STEM implementation.

Table 10. Essential Resources for Developing STEM Competence

Quote	Code	Category	Theme
"Workshops and training sessions are the best way to start improving STEM teaching skills." (T1, T3)	Workshops/ Training	Structured Professional Development	Professional development through structured training
"Attending training programs helps teachers gain new strategies and knowledge for STEM instruction." (T5)	Skill-building through training		
"Collaborating with colleagues and participating in professional networks helps us learn innovative STEM approaches." (T6, T8)	Collaboration; Networking	Collaborative Learning and Networking	Professional growth through collaboration and digital resources
"Access to online tools, videos, and digital platforms supports the enhancement of our STEM teaching." (T10)	Digital resources		
"Printed materials, teaching guides, and professional learning communities provide continuous support for STEM teaching." (T11, T13)	Teaching guides; PLCs	Resources and Continuous Learning	Continuous learning through resources and communities
"Having reliable reference materials helps sustain our knowledge and improve instructional practice." (T15)	Reference materials; Ongoing support		

Teachers identified several resources to enhance their STEM teaching. Some (T1, T3, T5) emphasized workshops and formal training as essential for building knowledge and instructional skills, which aligns with Bybee (2013), who highlights professional development as a key factor in effective STEM education. Others (T6, T8, T10) valued collaboration, networking, and digital resources, reflecting the importance of peer support and technology in teacher growth (Margot & Kettler, 2019). However, several teachers (T11, T13, T15) highlighted the role of printed materials, teaching guides, and professional learning communities in providing continuous support, consistent with Darling-Hammond et al. (2017), who argue that ongoing access to resources and communities strengthens instructional practice.

5.4 Pedagogical Content Knowledge (PCK) on STEM Education

In STEM education, Pedagogical Content Knowledge (PCK) emphasizes the crucial role it plays in helping teachers effectively integrate STEM concepts into their lessons. It serves as a framework that bridges content mastery and pedagogical expertise, enabling teachers to design meaningful learning experiences that connect scientific principles to real-world applications. In this context, PCK entails a deep understanding of how teaching strategies, content knowledge, and students' ways of learning interact within the STEM teaching approach. It also involves the ability to select appropriate instructional methods, assessment tools, and learning activities that foster critical thinking, creativity, and problem-solving among students. By developing strong PCK, teachers become more capable of facilitating interdisciplinary learning and nurturing students' interest and competence in science, technology, engineering, and mathematics.

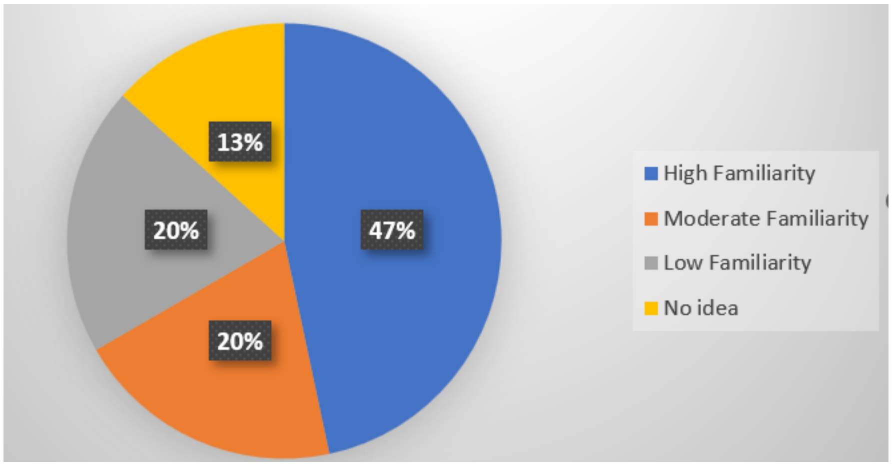

Figure 2. Familiarity with PCK in STEM Education

The results show varied levels of familiarity with Pedagogical Content Knowledge (PCK) among teachers. Approximately 47% demonstrated high familiarity with PCK in STEM education and actively applied PCK in planning inquiry-based and integrated STEM lessons, reflecting Shulman's (1986) idea of transforming content into teachable forms and Magnusson, Krajcik, and Borko's (1999) emphasis on PCK as central to inquiry-based teaching, about 23% showed moderate familiarity and expressed openness to training and workshops, echoing Van Driel, Verloop, and De Vos (1998) and Park and Chen (2012), who stress that professional development is crucial for strengthening PC and gradual learning through seminars and peer collaboration, reflecting Gess-Newsome's (2015) assertion that PCK evolves through experience and reflective practice, and about 23% had low familiarity which supports Kind's (2009) and Nilsson's (2008) findings that teachers often struggle to bridge theory and practice and with only around 7.7% falling into the 'no-idea' category. This spread aligns with broader research that shows while many teachers have some awareness of pedagogical-content knowledge (PCK), a substantial portion still struggle to integrate it meaningfully into classroom practice (Mientus et al.,2022).

Table 11. Importance of PCK in STEM Learning

Quotes (from Teachers)	Code	Category	Theme
"PCK is very important for effective teaching and meaningful student learning." (T1, T2, T5)	Essential for effective teaching and meaningful learning	Fundamental Value of PCK	High Recognition of PCK Importance
"Understanding PCK helps me design lessons that improve learning outcomes." (T3, T6)			
"PCK is important as it guides instruction and helps address students' needs." (T8, T9)			
"Knowing PCK allows me to plan lessons more effectively." (T4, T10, T11)	Guides instruction and	Instructional Guidance and	Moderate Recognition of

Quotes (from Teachers)	Code	Category	Theme
	supports student learning	Lesson Planning	PCK Importance
"PCK is somewhat important, but its impact depends on context and support." (T7, T12, T13)			
"The usefulness of PCK varies depending on available resources and class conditions." (T14, T15)	Contextual and conditional relevance	Conditional Application of PCK	Conditional Recognition of PCK Importance

Teachers recognized varying levels of importance of Pedagogical Content Knowledge (PCK) in enhancing STEM learning. Some considered PCK highly important for effective teaching and meaningful learning, consistent with Shulman's (1986) assertion that PCK is central to instructional success. Others acknowledged its importance in guiding instruction and addressing student needs, supporting Park et al.'s (2011) view that PCK helps tailor teaching to learners. Meanwhile, a few teachers also saw its relevance as conditional, depending on context and support, aligning with Gess-Newsome (2015), who emphasizes that PCK's effectiveness can be influenced by classroom and institutional factors.

Table 12. PCK's Role in Effective STEM Instruction

Quotes (from Teachers)	Code	Category	Theme
"PCK is essential for connecting content knowledge with the right teaching strategies to make complex concepts understandable." (T1, T2, T4)	Linking content with pedagogy for clarity	Content-Pedagogy Alignment	Facilitating Conceptual Understanding
"Using PCK helps me simplify STEM concepts for students." (T3, T5)			
"PCK guides me in addressing student misconceptions and promoting inquiry-based learning." (T6, T7, T10)	Guiding instruction, addressing misconceptions, promoting inquiry	Instructional Guidance and Misconception Management	Guiding Instruction and Inquiry
"It helps select effective activities that engage students in STEM learning." (T8, T9, T15)			
"PCK allows me to adapt lessons to student needs and foster engagement." (T11, T12)	Adapting lessons, linking content to real-life, promoting engagement	Student-Centered and Contextualized Instruction	Adapting Instruction for Student-Centered Learning
"It helps connect STEM content to real-life applications for better learning." (T13, T14)			

Teachers described the role of Pedagogical Content Knowledge (PCK) in STEM teaching in multiple ways. Some teachers emphasized its role in linking content knowledge with appropriate teaching strategies to simplify complex concepts, supporting Shulman's (1986) idea that PCK bridges subject matter and pedagogy. Others viewed PCK as a guide for addressing misconceptions and promoting inquiry, aligning with Park et al. (2011), who highlight PCK's role in selecting effective learning activities.

Meanwhile, several teachers also believed PCK helps adapt lessons to student needs, foster engagement, and connect STEM content to real-life applications, consistent with Gess-Newsome (2015), who notes that PCK supports student-centered and contextually relevant instruction.

Table 13. Teachers' Views on Merging Content and Pedagogy in STEM

Quotes (from Teachers)	Code	Category	Theme
"I will blend content from science, technology, engineering, and math with suitable teaching methods to make learning meaningful." (T1, T2, T5) "Integrating STEM requires combining subject knowledge with effective pedagogy." (T3)	Blending content and pedagogy	Content-Pedagogy Integration	Integration of Content and Teaching Strategies for Meaningful Learning
"I somehow design activities and lessons that promote critical thinking, problem-solving, and real-world application." (T6, T7) "STEM integration involves creating tasks that connect concepts to practical situations." (T9, T13)	Designing learning experiences for skills development	Designing Learning for Skills and Application	Promoting Critical Thinking and Real-World Application
"I probably use diverse strategies to connect interdisciplinary concepts and actively engage students." (T4, T11, T12) "Integrating STEM helps students understand concepts more deeply through varied approaches." (T8, T10, T14, T15)	Using multiple strategies for engagement and deeper understanding	Varied Instructional Strategies for Engagement	Supporting Interdisciplinary Learning and Active Engagement

Teachers expressed varied understandings of integrating subject knowledge and teaching strategies in STEM education. They emphasized blending content across science, technology, engineering, and math with effective teaching methods to make learning meaningful, aligning with Shulman's (1986) concept of Pedagogical Content Knowledge. Others highlighted designing activities that promote critical thinking, problem-solving, and real-world application, consistent with Bybee's (2013) emphasis on authentic STEM learning experiences. Meanwhile, several teachers (T11–T15) focused on using diverse strategies to connect interdisciplinary concepts and actively engage students, supporting Kolodner et al.'s (2003) view that integrated approaches enhance deep understanding and engagement.

Table 14. Key Aspects of PCK that Enhance STEM Teaching and Learning

Quotes (from Teachers)	Code	Category	Theme
"Understanding student misconceptions helps me correct false beliefs, adjust strategies, and design better assessments for deeper learning." (T1, T4, T9) "Addressing misconceptions allows timely interventions to enhance learning outcomes." (T6, T12)	Addressing misconceptions; timely interventions	Misconception Management and Instructional Adjustment	Correcting Misconceptions and Enhancing Learning

Quotes (from Teachers)	Code	Category	Theme
"I design hands-on, inquiry-based, and open-ended experiments to promote critical thinking and problem-solving." (T2, T7, T15)	Hands-on and inquiry-based learning; promoting skills	Experiential and Skills-Oriented Learning	Promoting Critical Thinking, Problem-Solving, and Creativity
"Such activities also foster creativity, collaboration, and scientific inquiry." (T10, T13)			
"Integrating technology, like digital tools and simulations, enhances visualization and engagement." (T3, T5)	Technology integration; digital tools; personalized learning	Technology-Enhanced Instruction	Enhancing STEM Instruction through Technology
"Personalized learning platforms improve accessibility and the effectiveness of STEM instruction." (T8, T11, T14)			

Teachers highlighted several strategies for effective STEM instruction. While some emphasized on understanding and addressing student misconceptions to adjust strategies, design assessments, and provide timely interventions, consistent with Duit and Treagust (2003), who stress that conceptual understanding is key to effective learning. Others also focused on hands-on, inquiry-based, and open-ended experiments to foster critical thinking, problem-solving, creativity, and collaboration, supporting Kolodner et al.'s (2003) view that active engagement enhances STEM skills. Meanwhile, several teachers mainly highlighted integrating technology, such as digital tools, simulations, and personalized learning platforms, to enhance visualization, engagement, and instructional effectiveness, aligning with Honey et al., (2014) on the role of technology in STEM learning.

Table 15. Teachers' Openness to Classroom Observations for Assessing PCK in STEM Education

Quotes (from Teachers)	Code	Category	Theme
"I am willing to participate in classroom observations to enhance my teaching and foster professional growth." (T1, T2, T7)	Willingness to improve teaching; seeking feedback	Positive Attitudes toward Professional Development	Positive Perception: Classroom Observations as Opportunities for Professional Growth
"Observations help me reflect on my strategies, get constructive feedback, and refine my instruction." (T3, T8)			
"I see classroom observations as valuable for identifying strengths and areas for improvement in STEM instruction." (T4, T5, T10)	Reflection and alignment with STEM teaching	Professional Growth through Reflection and STEM Alignment	Positive Perception: Classroom Observations as Opportunities for Professional Growth
"They help me apply PCK effectively and align lessons with STEM goals." (T6, T9, T11)			
"I am uncomfortable being observed and prefer self-assessment." (T13, T14)	Reluctance due to discomfort or disruption	Negative Attitudes and Preference for	Negative Perception: Preference for

Quotes (from Teachers)	Code	Category	Theme
"Observations may disrupt teaching flow and classroom dynamics." (T12, T15)		Alternative Approaches	Alternatives to Classroom Observations

Teachers expressed mixed perceptions of classroom observations. Mostly, viewed them positively as opportunities for professional growth, reflection, and improving STEM instruction, aligning with Darling-Hammond et al. (2017), who highlight that structured observation and feedback support teacher development. Others were somewhat reluctant, citing discomfort and potential disruption of teaching, which reflects insights from Tillema (2011) that teacher receptivity to observations can be influenced by anxiety and classroom dynamics. Overall, while observations can enhance instructional practices, careful implementation and support are needed to ensure teacher comfort and effectiveness.

5.5 Professional Development Needs

This section entails the professional needs and types of support that teachers require for future training programs on PCK and STEM education. It emphasizes the specific areas where teachers seek to strengthen their pedagogical content knowledge, instructional design, and integration of interdisciplinary approaches in the classroom. Moreover, this section highlights the importance of continuous professional development, mentoring, and collaborative learning communities to ensure that teachers are well-equipped to apply PCK and STEM principles effectively in their teaching practice. By identifying these needs, the study aims to inform the development of targeted capacity-building programs that will enhance teachers' competence, confidence, and innovation in delivering quality STEM-oriented instruction.

Table 16. Teachers' Interest in Professional Development on STEM Learning Approaches

Quotes (from Teachers)	Code	Category	Theme
"I am eager to join STEM professional development to improve my teaching competence and effectiveness." (T1, T2, T11)	Eagerness to improve skills; professional growth	Professional Growth and Skill Enhancement	Positive Perception: STEM Professional Development for Skill Enhancement
"Participating in STEM training helps broaden my knowledge and enhance instructional skills." (T4, T7, T9)			
"I want STEM training to help innovate my classroom practices and integrate technology confidently." (T3, T5) "It helps me engage students and design better learning activities." (T6, T8, T10, T12)	Innovation; updating strategies; technology integration	Motivation for Innovation and Instructional Improvement	Motivation for Innovation and Updated STEM Strategies
"STEM professional development is not my current priority; I prefer to focus on existing methods." (T13, T14)	Low prioritization; focus on other areas	Low Interest or Prioritization	Low Interest or Prioritization of STEM Professional Development
"I would rather concentrate on other teaching areas than attend STEM training now." (T15)			

Teachers expressed varying motivations toward STEM professional development. In general teachers, were eager to participate to enhance teaching competence and instructional effectiveness, consistent with Darling-Hammond et al. (2017), who note that professional development strengthens teacher skills and student outcomes. Others sought training to innovate classroom practices, integrate technology, and apply updated strategies, aligning with Bybee (2013), who emphasizes that continuous STEM learning promotes creativity and engagement. However, a few teachers did not prioritize STEM professional development, preferring to focus on existing methods, reflecting Tillema's (2011) observation that teacher engagement in professional growth depends on perceived relevance and readiness.

Table 17. Teachers' Perceptions on the Necessity of STEM Education Training

Quotes (from Teachers)	Code	Category	Theme
"STEM training helps design interdisciplinary lessons and hands-on activities that connect learning to real-world contexts." (T1, T6) "It enables collaborative projects that make lessons relevant to students' lives." (T9, T15)	Real-world applications; interdisciplinary learning	Application-Oriented and Interdisciplinary Teaching	Promoting Real-World Problem Solving and Applications
"STEM training is essential to keep up with technological advancements and emerging teaching strategies." (T2, T8) "It helps me stay updated with curriculum shifts in global education." (T11)	Staying current with technology and curriculum	Professional Development for Technological and Curriculum Updates	Keeping Pace with Technological and Educational Changes
"STEM training fosters inquiry-based learning, problem-solving, and design thinking." (T3, T4) "It makes STEM subjects more meaningful for students through critical thinking activities." (T14)	Inquiry, problem-solving, design thinking	Inquiry-Based and Skills-Oriented Learning	Fostering Critical Thinking, Inquiry, and Problem-Solving Skills
"STEM training strengthens teacher skills and builds confidence in teaching complex concepts." (T5, T10) "It improves student learning outcomes in STEM subjects." (T13)	Teacher competence; student performance	Teacher Skill Development and Effectiveness	Enhancing Teacher Competence and Student Learning Outcomes
"STEM training helps nurture creativity, innovation, and essential 21st-century skills in learners." (T7, T12)	21st-century skills	21st-Century Skills Development	Developing 21st-Century Skills

Teachers identified multiple reasons for the importance of STEM training. Some emphasized designing interdisciplinary, hands-on lessons that connect learning to real-world contexts (T1, T6, T9, T15), consistent with Bybee (2013), who highlights authentic STEM experiences as essential for meaningful learning. Others valued staying updated with technological advancements and curriculum changes (T2, T8, T11), aligning with Honey et al., (2014) on the need for continual adaptation in STEM education. Several teachers focused on fostering inquiry, problem-solving, and critical thinking skills (T3, T4, T14), while others highlighted improving teacher competence and student outcomes (T5, T10, T13), and some underscored nurturing creativity and 21st-century skills (T7, T12), reflecting the broad pedagogical goals of STEM integration (Shulman, 1986; Kolodner et al., 2003).

Table 18. Teachers' Needs for Effective Support in Enhancing Teaching Ability

Quotes (from Teachers)	Code	Category	Theme
"We need ongoing professional development, updated STEM curriculum, and continuous skills enhancement opportunities." (T1, T8)	Continuous training; updated resources	Ongoing Professional Development and Resource Updates	Continuous Professional Development and Updated Materials
"Access to online platforms and instructional materials helps improve our teaching effectiveness." (T10, T15) "Innovative workshops, mentoring from experienced educators, and technology integration support are essential." (T2, T5)	Training, mentoring, research collaboration	Structured Workshops, Mentoring, and Collaborative Learning	Training, Workshops, and Mentoring
"Exposure to teaching innovations and research collaboration helps us grow professionally." (T13, T14)			
"Hands-on seminars, modern lab equipment, STEM kits, and instructional technology tools are necessary." (T3, T6)	Practical resources; hands-on learning	Hands-On Learning and Adequate Resources	Hands-On Learning and Adequate Resources
"Access to sufficient teaching aids enhances hands-on STEM learning." (T9, T12)			
"Collaborative learning communities, peer sessions, and regular feedback improve our teaching practices." (T4, T8) "Active participation in professional groups helps share ideas and strategies." (T15)	Collaboration; feedback	Peer Collaboration and Professional Feedback	Collaboration and Feedback
"Supportive school leadership, administrative assistance, and funding are needed for classroom projects." (T9, T11) "More preparation time allows us to better implement STEM activities." (T12)	Leadership support; funding; preparation time	Institutional and Leadership Support	Support from Leadership and Funding
"Opportunities to pursue advanced studies, attend conferences, and engage in research are valuable." (T7, T13)	Advanced studies; professional exposure	Advanced Professional Learning and Academic Exposure	Opportunities for Advanced Studies and Conferences

Teachers identified several key needs to improve STEM teaching. Some (T1, T8, T10, T15) emphasized continuous professional development and access to updated curriculum materials, aligning with Darling-Hammond et al. (2017), who highlight ongoing training as critical for teacher growth. Others (T2, T5, T13, T14) valued workshops, mentoring, and exposure to teaching innovations, supporting Bybee's (2013) view that collaborative professional learning enhances instructional practices. Many teachers (T3, T6, T9, T12) stressed hands-on learning and adequate resources, consistent with Honey, Pearson, and Schweingruber (2014) on the importance of practical STEM materials. Collaboration and feedback (T4, T8, T15), leadership support and funding (T9, T11, T12), and opportunities for advanced studies or conferences (T7, T13) were also noted as essential for effective STEM instruction and teacher development.

Table 19. Teachers' Interest in Exploring Specific Topics in STEM Education

Quotes (from Teachers)	Code	Category	Theme
"We want to explore project-based, inquiry-based, interdisciplinary, and problem-solving strategies in STEM." (T1, T4) "Collaborative projects and design thinking help enhance STEM learning." (T5, T6, T9)	Innovative teaching strategies; collaboration	Active, Collaborative, and Innovative Teaching Approaches	Innovative Teaching Strategies in STEM
"Incorporating technology like coding, robotics, AI, and simulations improves STEM instruction." (T2, T7) "Using engineering design processes and modeling engages students effectively." (T8, T10)	Technology integration; digital tools	Technology-Enhanced Instruction	Technology Integration in STEM
"Connecting STEM learning to real-life situations and environmental issues makes it meaningful." (T3, T13) "Relating lessons to STEM career pathways helps students see practical applications." (T12, T14)	Contextualization; real-world relevance	Contextualized, Real-World, and Career-Relevant Learning	Contextual and Real-World Applications of STEM
"We need strategies to assess STEM learning effectively and foster creativity." (T11, T15)	Assessment strategies; learner development	Assessment-Oriented and Learner-Centered Strategies	Assessment and Learner Development in STEM

Teachers highlighted key focus areas for enhancing STEM teaching. Some (T1, T4, T5, T6, T9) emphasized innovative teaching strategies, including project-based, inquiry-based, and collaborative learning, aligning with Kolodner et al. (2003), who highlight the effectiveness of problem-solving and design thinking in STEM education. Others (T2, T7, T8, T10) prioritized technology integration, such as coding, robotics, simulations, and engineering design processes, consistent with Honey, Pearson, and Schweingruber (2014) on the importance of digital tools for engagement and learning. Several teachers (T3, T12, T13, T14) focused on connecting STEM lessons to real-world contexts and career pathways, while others (T11, T15) stressed effective assessment strategies to foster creativity and learner development, supporting Bybee's (2013) emphasis on authentic and student-centered STEM learning.

Table 20. Preferred Professional Development Activities for Enhancing STEM Teaching

Quotes (Teachers' Responses)	Code	Category	Theme
"Workshops and seminars with hands-on STEM activities and real-world applications help us collaborate and integrate effectively." (T1, T4)	Hands-on training; real-world application	Practical and Experiential STEM Training	Practical and Hands-On STEM Professional Development
"Professional development should include practical, interdisciplinary lessons connected to real-life contexts." (T3, T9)			
"We need personalized coaching and mentoring with classroom observation, lesson design support, and feedback." (T2, T8)"Feedback and guidance from mentors improve STEM classroom implementation." (T7, T10)	Coaching; mentoring; feedback	Personalized Guidance and Mentorship	Coaching and Mentoring for Skill Enhancement
"Peer learning communities and STEM circles help us share teaching experiences and best practices." (T6, T12)	Peer collaboration; shared practices	Collaborative Professional Learning	Collaboration and Peer Learning Communities
"Collaborative lesson planning and reflection with peers strengthens STEM teaching." (T4, T13)			
"Training should provide updated STEM knowledge and pedagogical strategies aligned with current research." (T2, T14) "We need continuous access to updated content with teaching applications." (T8) "We want training that fosters creativity, innovation, problem-solving, and inquiry-driven learning." (T5, T12)	Updated STEM knowledge; pedagogy integration	Continuous Content and Pedagogy Updates	Updated STEM Content with Pedagogical Applications
	Student-centered; inquiry-based approaches	Student-Centered and Inquiry-Based Approaches	Student-Centered and Inquiry-Based STEM Approaches
"We need exposure to technological tools that support effective STEM teaching." (T6)	Technology integration	Technology-Enhanced Instruction	Integration of Technological Tools in STEM Instruction
"Sustained follow-up sessions ensure mastery and proper application of STEM strategies." (T11)"Encouraging experimentation and risk-taking in teaching helps us innovate." (T15)	Continuous support; innovative teaching	Ongoing Support and Encouragement for Innovation	Sustained Support and Encouragement for Innovation

Teachers emphasized diverse professional development needs in STEM. Some preferred hands-on and real-world training, aligning with Kolodner et al., (2003), who stress the value of project- and problem-based learning. Others highlighted coaching and mentoring, consistent with Darling-Hammond et al., (2017), also emphasize feedback and guidance for teacher growth. Collaboration through peer learning was also valued, echoing Bybee (2013) on shared practices in STEM education. Additionally, teachers requested updated STEM content with pedagogy, while others sought student-centered, inquiry-based approaches, supporting Honey, Pearson, and Schweingruber (2014) on fostering creativity and problem-solving. Finally, several teachers stressed the need for technology integration and continuous support, aligning with Mishra & Koehler's (2006), TPACK framework for effective tech-enhanced STEM teaching.

6. Suggestion

1. Implement school-based PCK+STEM training- with hands-on workshops, digital skills development, and ongoing coaching to equip teachers with practical strategies, assessment tools, and sustainable classroom application.
2. Integrate PCK and STEM into the biology curriculum- through policy alignment, curriculum mapping, instructional materials, and digital resources, supported by teacher orientation and evaluation mechanisms.
3. Develop and share PCK+STEM lesson exemplars for biology teachers- using digital tools and interactive platforms to connect scientific concepts with real-world applications and foster innovative teaching.
4. Establish a monitoring and evaluation system-to track teachers' digital competence, instructional improvement, and program impact, guiding future professional development and policy improvements.

7. Conclusion

The findings of the study reveal that teachers possess varying levels of knowledge and understanding of STEM education as a teaching approach. Many teachers recognize the importance of integrating science, technology, engineering, and mathematics to promote higher-order thinking skills, problem-solving abilities, and the application of knowledge to real-world contexts. However, the depth of their understanding and ability to apply these concepts effectively in classroom settings differ significantly. While some teachers demonstrate a clear grasp of how to connect STEM principles across disciplines, others exhibit limited awareness of how to translate these ideas into practical, student-centered learning experiences. In terms of teaching practices, teachers employ a range of instructional strategies aimed at facilitating student learning in science lessons. These include traditional lecture-based methods as well as more engaging approaches such as inquiry-based learning, hands-on experimentation, and collaborative group work. Teachers who are more knowledgeable about STEM education tend to design lessons that are more interactive and connected to real-life problems, allowing students to develop creativity, critical thinking, and teamwork skills. Nevertheless, inconsistencies in implementing STEM-oriented practices indicate a continuing need for professional support and structured guidance.

In relation to professional development, teachers strongly expressed the need for ongoing training and capacity-building programs focused on Pedagogical Content Knowledge (PCK) and STEM integration. They identified specific areas for improvement, such as lesson design, interdisciplinary teaching, and the use of technology and assessment tools aligned with STEM principles. Continuous mentoring, peer collaboration, and participation in workshops or learning communities were also seen as essential supports for improving instructional competence and confidence. Despite their enthusiasm for adopting STEM and PCK approaches, teachers encounter several challenges that hinder full implementation, including a lack of instructional materials, limited access to technology, time constraints, and curriculum misalignment with STEM objectives. However, they also acknowledged the presence of supportive resources such as administrative encouragement, teamwork among colleagues, and the availability of some technological tools that facilitate lesson delivery.

Overall, the findings highlight that Pedagogical Content Knowledge (PCK) serves as the foundation for effective STEM education, as it enables teachers to integrate content mastery, pedagogical strategies, and an understanding of students' learning processes. Notably, teachers with well-developed

PCK are better equipped to design meaningful, inquiry-based, and interdisciplinary learning experiences that cultivate curiosity, innovation, and problem-solving skills among students—ultimately advancing the goals of 21st-century STEM education.

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