

## Developing Thai Second-year Elementary Student Teachers' Technological Pedagogical Content Knowledge for STEM Integration through Micro-Teaching

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### ABSTRACT

Technological Pedagogical Content Knowledge (TPCK) serves as a framework for integrating technology into teaching. It has significant implications for teachers and teacher educators. The purposes of this study were to study 1) The development of Thai second-year elementary student teachers' TPCK for STEM Integration through Micro-teaching. 2) The satisfaction with STEM integration through Micro-Teaching. The samples comprised 30 Thai second-year elementary student teachers who enrolled in the Science and Technology for Elementary Education Teachers course, which was conducted during the first semester of 2023, at Surindra Rajabhat University, which was located in the North Eastern Part of Thailand. This study employed both qualitative and quantitative data collection methods to explore the development of TPCK among second-year Thai elementary student teachers. The instruments were the questionnaire on TPCK development with semi-structured interviews and the questionnaire on satisfaction with STEM integration through Micro-Teaching, 5-point Likert Scale format. Multiple data sources consisted of classroom observation, semi-structured interviews on the student teachers' lesson plans, micro-teaching practices, reflective journals, and document reviews. The data was analyzed by mean and standard deviation. The results revealed that 1) the development of Thai second-year elementary student teachers' TPCK for STEM Integration overall was at a high level. The component with the highest level and the highest average scores was Technological Knowledge (TK). The component with the lowest level was Technological Content Knowledge (TCK), respectively. 2) The satisfaction with STEM integration through Micro-Teaching overall was at a high level. The item with the highest level and the highest average scores was integrating STEM promotes student-centered learning. The item with the lowest level was developing appropriate STEM-integrated learning activities for various student groups, respectively.

**Keywords:** TPCK, STEM Integration, Micro-teaching, Science and Technology for Elementary Education Teachers Course, Teacher Education.



## Introduction

Technological Pedagogical Content Knowledge (TPCK) serves as a framework outlining the types of knowledge teachers need to teach with technology and how these knowledge areas interact. This framework is informed by three primary bodies of knowledge: technological knowledge, content knowledge, and pedagogical knowledge (Koehler and Mishra, 2008). It builds on Shulman's (1986) concept of pedagogical content knowledge (PCK), as a distinctive body of knowledge for teaching. PCK is an acknowledgment of the importance of the transformation of subject matter knowledge per se into subject matter knowledge for teaching. He defined PCK as the amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding. The TPCK framework expands Shulman's notion by incorporating technological knowledge. The inclusion of technology adds further complexity to teaching because of its rapidly evolving nature (Koehler and Mishra, 2008). Teachers need to understand how technology, pedagogy, and content knowledge interact to form an integrated knowledge base that exceeds the individual elements. Effective teaching with technology requires a flexible framework to demonstrate how quickly evolving technologies can be integrated with various teaching methods and subject areas. According to STEM Education, it was found that STEM education significantly enhances students' problem-solving skills and fosters a deeper understanding of integrated subjects. STEM Education is an interdisciplinary approach that integrates the teaching of four major disciplines: Science (S), Technology (T), Engineering (E), and Mathematics (M). It combines the strengths and unique teaching methods of each field to provide a holistic learning experience. The goal is for students to use knowledge

from all these areas to solve problems, conduct research, and innovate in response to current global challenges. STEM education relies on the engineering design process. The STEM learning process includes six steps: Identify the Problem, Research and Gather Information, Design Solutions, Plan and Implement Solutions, Test, Evaluate, and Improve, and Present Solutions (The Institute for the Promotion of Teaching Science and Technology (IPST), 2017). One of the critical challenges in teacher education today is ensuring that student teachers are not only knowledgeable in their content areas but also skilled in integrating technology effectively into their teaching. Despite the theoretical emphasis on TPCK, many student teachers struggle with the practical application of these concepts in real classroom settings (Tanak, 2020). This challenge is particularly evident in the integration of technology within STEM subjects, where the complexity of content often exacerbates difficulties in selecting and applying appropriate technological tools (Angeli & Valanides, 2009; Niess, 2011). Although previous studies have explored the development of TPCK among student teachers, there is a notable gap in research focusing on the specific mechanisms through which TPCK is developed during micro-teaching sessions, especially within the context of STEM education. Micro-Teaching, as a reflective and iterative practice, provides a unique opportunity for student teachers to develop and refine their TPCK. However, existing literature has not adequately addressed how this process occurs, particularly in the Thai educational context, where educational practices and challenges may differ from those in Western settings (Chai, Koh, & Tsai, 2013). This study draws on the TPCK framework developed by Koehler & Mishra (2008), which emphasizes the interconnectedness of technology, pedagogy, and content



knowledge in effective teaching. The TPCK framework serves as the theoretical foundation for understanding how student teachers integrate these three components in their teaching practices. Furthermore, this study is informed by the concept of reflective practice (Schön, 1983), which is integral to Micro-Teaching, allowing student teachers to critically evaluate and improve their teaching strategies through repeated practice and feedback. By addressing these gaps, this study aims to contribute to the body of knowledge on TPCK development, particularly in the context of STEM education, and to provide practical insights for enhancing teacher education programs in Thailand and similar contexts.

This research initiative aligns with the strategic vision of Surindra Rajabhat University, which has outlined a five-year strategic plan (2023-2027) encompassing four key strategies:

1. Local Development Strategy: "Enhancing local excellence through research, innovation, arts, culture, and wisdom."
2. Teacher Development Strategy: "Producing innovative teachers and creating learning innovations to meet world-class standards, aiming to become a regional hub."
3. Education Quality Enhancement Strategy: "Elevating the quality of learning and fostering innovations that add value and international recognition."
4. Management Strategy: "Developing management systems and personnel towards becoming a sustainable university for local development with international standards."

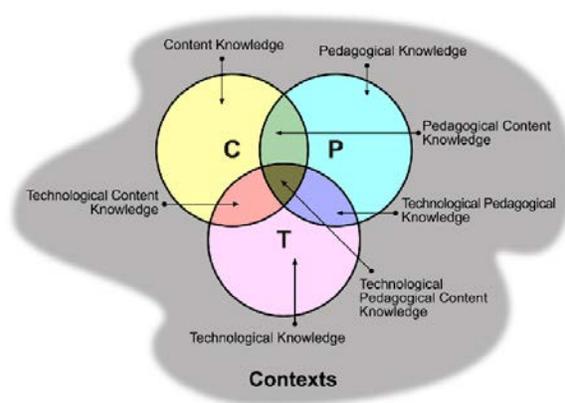
Given this context, the author is particularly interested in developing the Technological Pedagogical Content Knowledge of Thai second-year elementary student teachers for STEM integration through Micro-Teaching. This research seeks to address the identified gap and contribute to the strategic goals of Surindra Rajabhat University by fostering innovative teaching practices and enhancing educational quality.

The purposes of this study were to: 1) study the development of Thai second-year elementary student teachers' TPCK for STEM integration through the Micro-Teaching in Science and Technology for Elementary Education Teachers course, conducted during the first semester of 2023 at Surindra Rajabhat University. 2) study the satisfaction with STEM integration through Micro-Teaching of Thai second-year elementary student teachers, who enrolled in Science and Technology for Elementary Education Teachers course.

### Literature Review

Shulman (1987) identified seven domains of teacher knowledge, highlighting the complexity of the teaching process which demands the application of diverse knowledge areas. These domains include content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of educational ends, purposes, and values. So that it can be used effectively and flexibly in the communication process between teachers and learners during classroom practice. TPCK extends Shulman's PCK by incorporating technological knowledge, demonstrating how technological tools can transform pedagogical strategies and content representations for specific topics (Koehler, et al. ,2007; Koehler & Mishra, 2008). In the TPCK framework, what teachers need to know is characterized by three broad knowledge bases-technology, pedagogy, and content- and the interactions between and among these knowledge bases. In this approach, technology in teaching is characterized as something well beyond isolated knowledge of specific hardware or software. Rather, technology that is introduced into teaching contexts "causes the representation of new concepts and requires developing

a sensitivity to the dynamic, transactional relationship between all three components” (Koehler & Mishra, 2005a). Good teaching with technology, therefore, cannot be achieved by simply adding a new piece of technology upon existing structures. Good teaching, with technology, requires a shift in existing pedagogical and content domains. In the past decade, many researchers have highlighted the importance of supporting pre-service teachers’ professional development for technology integration (Flick & Bell, 2000; Jang & Chen, 2010). Koehler *et al.* (2007) describe TPCK as a situational form of knowledge necessary for the intelligent use of technology in teaching. Teachers and teacher educators must explicitly teach how to use technology to transform specific content for specific learners and address the interactions among technology, content, pedagogy, and learners. TPCK is the conceptual framework for this study. Specifically, the author draws upon Koehler & Mishra (2008) as the basis for the decision to focus attention on the TPCK framework and its knowledge components (see Figure 1), knowing how Thai second-year elementary student teachers integrate those components during their Micro-Teaching experiences. The TPCK framework highlighted the complexity of teaching in the digital age and the need for teachers to be proficient in all three areas-content, pedagogy, and technology. Effective teaching requires the ability to integrate these domains seamlessly.



**Figure 1** Technological Pedagogical Content Knowledge (TPCK) framework and its knowledge components (Koehler & Mishra, 2008)

The Technological Pedagogical Content Knowledge (TPCK) framework, proposed by Koehler & Mishra (2008), is an extension of Shulman's idea of Pedagogical Content Knowledge (PCK). TPCK emphasizes the integration of technology in teaching, recognizing that effective teaching lies at the intersection of technology, pedagogy, and content knowledge. The framework helps educators understand how these components interact to create an effective teaching and learning environment. Here is an overview of the knowledge components within the TPCK framework drawn upon this research:

### 1. Content Knowledge (CK)

**Definition:** Understanding the subject matter that is to be taught.

**Example:** A science teacher must know scientific concepts, principles, and theories in subjects like biology, chemistry, and physics.

### 2. Pedagogical Knowledge (PK)

**Definition:** Understanding the methods and processes of teaching and learning. This includes knowledge of classroom



management, lesson planning, assessment, and understanding how students learn.

**Example:** Knowledge of different teaching strategies, such as collaborative learning, and inquiry-based learning.

### 3. Technological Knowledge (TK)

**Definition:** Understanding how to use digital tools and resources effectively in the classroom.

**Example:** Proficiency in using educational software, online resources, and digital assessment tools, and understanding how these can enhance learning.

### 4. Pedagogical Content Knowledge (PCK)

**Definition:** The intersection of pedagogy and content knowledge. It involves knowing how to teach specific content in a way that makes it comprehensible to students.

**Example:** A science teacher knows how to explain the concept of photosynthesis using analogies, experiments, and visual aids.

### 5. Technological Content Knowledge (TCK)

**Definition:** Understanding how technology can support and enhance the understanding of specific content.

**Example:** Using simulations and modeling software to teach complex scientific concepts such as cellular processes.

### 6. Technological Pedagogical Knowledge (TPK)

**Definition:** Understanding how teaching and learning can change when particular technologies are used in particular ways.

**Example:** Knowing how to design an online discussion that promotes critical thinking and engagement among students.

### 7. Technological Pedagogical Content Knowledge (TPCK)

**Definition:** The comprehensive understanding that emerges from the interaction of content, pedagogy, and technology. It involves knowing how to integrate technology into teaching in a way that enhances learning.

**Example:** Designing a science lesson that incorporates interactive simulations, aligns with pedagogical strategies that support inquiry-based learning, and addresses the specific content of the lesson.

## Methodology

This study employed a mixed methods research design, integrating both qualitative and quantitative approaches to comprehensively understand the development of Technological Pedagogical Content Knowledge (TPCK) among second-year Thai elementary student teachers. The qualitative data were collected through semi-structured interviews, classroom observations, reflective journals, and document reviews. These data were analyzed using thematic analysis, which involved coding to identify recurring themes and patterns related to TPCK development. This approach provided an in-depth understanding of the student teachers' experiences, the challenges they encountered, and their reflections on their teaching practices.

Quantitative data were gathered using questionnaires designed to assess TPCK development and satisfaction with STEM integration through Micro-Teaching, utilizing a 5-point Likert scale. The quantitative data were analyzed using descriptive statistics, including mean and standard deviation, to evaluate changes in the student teachers' TPCK levels following the micro-teaching sessions. This quantitative analysis offered a measurable assessment of TPCK development, effectively complementing the qualitative insights.

### 1. Samples and Setting

The population consisted of 2 classes, totaling 60 Thai second-year elementary student teachers enrolled in the Science and Technology for Elementary Education Teachers course, offered during the first semester of 2023



at the Faculty of Education, Surindra Rajabhat University. The sample comprised 30 of these student teachers. The author supervised the practice in 1 of the classes. The student teachers' major field of study was Elementary Education, which was taken in the Faculty of Education. Each group of student teachers was asked to write a STEM lesson plan and teach it the way they designed it through Micro-Teaching. These lesson plans integrated STEM by combining scientific concepts with engineering practices, mathematical analysis, and the use of technology to solve a real-world problem. Regarding the topics of their lesson plans: Water Rocket Activity, Fly Trap Activity, Wind-Powered Car Activity, Kite Flying Activity, Sailboat with Wind Activity, String Telephone Activity, Tin Can Telephone Activity, Exploring Properties of Everyday Materials Activity, Rubber Band Powered Car Activity, and Remote-Controlled Car Activity. The first author's role as the lecturer in the course, who observe and examine the second-year elementary student teachers' lesson plans and their document reviews during their Micro-Teaching. Micro-teaching was considered an important strategy for studying their TPCK development, and the satisfaction with STEM integration through Micro-Teaching was also evaluated.

Before their one-year teaching practice during the final fourth year of the Teacher Preparation Program, they all were required to pass all courses taken in education and their subject areas during the previous three years. Regarding the Science and Technology for Elementary Education Teachers course that was conducted during the first semester of 2023, in the Faculty of Education of Surindra Rajabhat University, this course is required for second-year elementary student teachers to be enrolled. The course description included Information reaching in biological science, physical science, world, astronomy,

and technology in primary education, understanding the scientific process, scientific method, scientific progress, and science in current events, unit design practice, design scientific experiment activities, learning plans, media, evaluation from learning resources and research Including new teaching methods that promote the creation of self-knowledge promote the process of scientific inquiry knowledge, scientific process skills, and scientific problem solving, method draw students' attention to lessons and inspiring students.

## 2. Data Collection

To study their TPCK development, and the satisfaction with STEM integration through Micro-Teaching, the second-year elementary student teachers were asked to design and write their lesson plans for STEM integration in groups, each group consisted of 3 people, after revising their lesson plans by the author, they were asked to prepare their teaching by Micro-Teaching relevant to the revised lesson plans. The multiple data sources were used in this study, the classroom lessons were observed and video recorded. The observed lessons for each group of student teachers took about 40 minutes in the period of time. They were also asked to reflect on their teaching practices after the class. All interviews were conducted in a semi-structured way that allowed them to tell their own successes and progress. In addition, the author also interviewed them after the lessons about their teaching. All the interviews were also recorded and transcribed verbatim. The documents as lesson plans, worksheets, learning materials, assignments, and reflective journals were reviewed as additional data in this study. After completing the Micro-Teaching, they were asked to complete the questionnaires on TPCK development and satisfaction with STEM integration through Micro-Teaching, using a 5-point Likert scale format.

### 3.3 Data Analysis

The data were analyzed using mean and standard deviation. Moreover, methodological triangulation was achieved through multiple data sources such as lesson plans, interview transcriptions, field notes, and document reviews. This process allowed the same data to be viewed from various perspectives, which clarified the meaning of the data in the larger context. The data from the questionnaires were analyzed using descriptive statistics, specifically the mean and standard deviation. The interpretation of the mean scores reflects Technological Pedagogical Content Knowledge development for STEM integration and the satisfaction with STEM integration through Micro-Teaching of Thai second-year elementary student teachers as the same as follows:

4.50 - 5.00: The development of TPCK for STEM integration is at the highest level.

3.50 - 4.49: The development of TPCK for STEM integration is at a high level.

2.50 - 3.49: The development of TPCK for STEM integration is at a moderate level.

1.50 - 2.49: The development of TPCK for STEM integration is at a low level.

## Results and Discussion

### 1. The development of Thai second-year elementary student teachers' TPCK for STEM Integration through Micro-teaching.

Regarding the development of Thai second-year elementary student teachers' TPCK for STEM integration through Micro-Teaching, the results are shown in Table 1.

**Table 1** The development of TPCK and its components of Thai second-year elementary student teachers

TPCK and its components	The development of TPCK for STEM integration among Thai second-year elementary student teachers			
	$\bar{X}$	S.D.	Meaning	rank
1. Content Knowledge (CK)	3.99	0.79	high	5
2. Pedagogical Knowledge (PK)	4.07	0.73	high	2
3. Technological Knowledge (TK)	4.20	0.73	high	1
4. Pedagogical Content Knowledge (PCK)	3.96	0.65	high	6
5. Technological Content Knowledge (TCK)	3.96	0.85	high	7
6. Technological Pedagogical Knowledge (TPK)	4.04	0.71	high	3
7. Technological Pedagogical Content Knowledge (TPCK)	4.02	0.68	high	4
total	4.03	0.72	high	

As can be seen in Table 1, the results revealed that the overall development of TPCK for STEM integration among Thai second-year elementary student teachers was at a high level ( $\bar{X}=4.03$ , S.D.=0.72). The total mean score of 4.03 with an S.D. of 0.72 indicates that the overall development of TPCK among the student teachers is high. This comprehensive score reflects their ability to integrate technology, pedagogy, and content knowledge effectively, preparing them to implement STEM education in their classrooms. The component with the highest level and the highest average scores was Technological Knowledge (TK) ( $\bar{X}=4.20$ , S.D.=0.73). The component with the lowest level was Technological Content Knowledge (TCK) ( $\bar{X}=3.96$ , S.D.=0.85), respectively. The results implied that the elementary student teachers understood clearly that it was difficult to implement the traditional instructional strategy as the lecture approach on some abstract units thus, they would



tend to incorporate technology in the instruction for STEM integration. The findings are consistent with the previous studies (Koehler & Mishra, 2008; Mishra, Koehler & Kereluik, 2009), which stated that Technological Knowledge (TK) highlights the understanding of how to use digital tools and resources effectively in the classroom including an understanding of how to use computer software and hardware, presentation tools such as document presenters and projects, and other technologies used in educational contexts. Most importantly, the teachers with extensive TK are capable of adapting to and learning new technologies. Moreover, Technological Content Knowledge (TCK), highlights the understanding of how technology can support and enhance the understanding of specific content. Technology not only influences what teachers know but also provides new ways to represent content that was previously impossible. Furthermore, technology facilitates the discovery of new content and representations. However, if the teachers lack TCK, it tends to lead to the implementation of unsuitable instructional strategies.

The analysis of the development of Technological Pedagogical Content Knowledge (TPCK) for STEM integration among Thai second-year elementary student teachers reveals several key insights. The results, based on the mean score ( $\bar{X}$ ) and standard deviation (S.D.), indicate a generally high level of TPCK development across various components, with specific strengths and areas for improvement.

**1.1 Technological Knowledge (TK):** Technological Knowledge (TK) received the highest ranking with a mean score of 4.20 and an S.D. of 0.73, indicating a high level of proficiency. This suggests that elementary student teachers are well-versed in utilizing technology, which is essential for integrating STEM effectively. Many student

teachers expressed that through the micro-teaching sessions, their confidence in integrating technology into their lessons significantly improved. One student teacher noted, "Before the course, I was hesitant to use digital tools, but now I feel much more capable of incorporating technology into my lessons effectively." The emphasis on TK aligns with the increasing importance of digital literacy in education, as highlighted by Mishra and Koehler (2006), who argue that understanding and applying technology is crucial for modern educators.

**1.2 Pedagogical Knowledge (PK):** Pedagogical Knowledge (PK) ranked second with a mean score of 4.07 and an S.D. of 0.73, also reflecting a high level of competence. This high ranking indicates that elementary student teachers possess strong foundational teaching skills, which are vital for implementing effective instructional strategies. Many student teachers reported a significant shift in their understanding of learner-centered teaching methods. One student teacher noted, "Before this course, I was more focused on delivering content, but now I see the importance of engaging students in the learning process, making sure they actively participate rather than just listening." According to Shulman (1987), PK involves general principles of teaching and classroom management, which are critical for creating conducive learning environments.

**1.3 Technological Pedagogical Knowledge (TPK):** Technological Pedagogical Knowledge (TPK) came in third with a mean score of 4.04 and an S.D. of 0.71. This component highlights the ability to integrate technology with pedagogical techniques, ensuring that technological tools are used effectively to enhance learning. Many student teachers reported that they learned how to better integrate technology with their pedagogical practices. For instance, one student teacher shared, "I realized that technology should not just be an



add-on but should be thoughtfully integrated to enhance the learning experience. For example, I started using interactive simulations to explain complex scientific concepts, which made the lessons more engaging and easier for students to grasp." This result is consistent with the findings of Angeli & Valanides (2009), who emphasize the importance of blending technology with pedagogy to create meaningful learning experiences.

#### 1.4 Technological Pedagogical Content Knowledge

**(TPCK):** The overall TPCK, which represents the intersection of technology, pedagogy, and content, scored a mean of 4.02 with an S.D. of 0.68. This high score indicates that elementary student teachers are capable of integrating all three knowledge domains to facilitate STEM education. Some student teachers provided specific examples of how they effectively integrated TPCK into their lessons. For instance, one student teacher described, "I used an interactive whiteboard to teach a science lesson. The technology allowed me to visually demonstrate complex processes, while the pedagogical approach of guided inquiry helped students explore the content more deeply." Moreover, reflective journals indicated that ongoing reflection was a key factor in the development of TPCK. One student teacher wrote, "Reflecting on my lessons allowed me to see where I was successfully integrating technology with pedagogy and content, and where I needed improvement. This reflection process was crucial in helping me develop my TPCK." This holistic understanding is crucial for fostering interdisciplinary learning and developing students' problem-solving skills (Koehler & Mishra, 2009).

**1.5 Content Knowledge (CK):** Content Knowledge (CK) was ranked fifth with a mean score of 3.99 and an S.D. of 0.79. While still high, this score suggests that there is room for improvement in the depth of content knowledge

among elementary student teachers. Many student teachers reported a significant improvement in their understanding of the core content they were teaching, particularly in STEM subjects. One student teacher noted, "I realized that to teach effectively, I needed to deepen my understanding of the content itself. This course pushed me to really study the material so that I could explain it clearly and confidently to my students." Some student teachers encountered difficulties when dealing with more complex topics within the curriculum. For instance, one student teacher shared, "I struggled with explaining certain scientific concepts, in a way that was both accurate and understandable for young students. It made me realize that I need to further solidify my own understanding before I can teach it effectively." Mastery of subject matter is fundamental for effective teaching, as it enables teachers to convey complex concepts clearly and accurately (Shulman, 1986).

**1.6 Pedagogical Content Knowledge (PCK):** Pedagogical Content Knowledge (PCK) and Technological Content Knowledge (TCK) both scored the lowest among the components, with mean scores of 3.96 (S.D. 0.65 for PCK and 0.85 for TCK). Despite the overall positive development, some student teachers struggled with effectively integrating PCK, particularly in balancing content rigor with student engagement. A student teacher mentioned, "I sometimes found it hard to simplify complex content without losing its essence. I wanted to make the lesson engaging, but I was concerned about oversimplifying the content." Moreover, some student teachers identified challenges in applying technology to specific content areas. The interviews revealed that some student teachers lacked confidence in their TCK skills, which impacted their ability to teach effectively using technology. Despite being familiar with certain technological



tools, they were unsure about how to apply them in a way that enhanced their understanding of the content. This gap in confidence was evident in statements like, "I know how to use the tools, but I'm not always sure I'm using them in the best way to help students grasp the material." These results indicate a need for further development in these areas. PCK is essential for understanding how to teach specific content effectively, while TCK involves using technology to represent and teach content (Graham, 2011).

**2. The satisfaction with STEM integration through Micro-Teaching of Thai second-year elementary student teachers.**

Regarding the satisfaction with STEM integration through Micro-Teaching, the results are shown in Table 2.

**Table 2** The satisfaction with STEM integration through Micro-Teaching of Thai second-year elementary student teachers.

Items	The satisfaction with STEM integration through Micro-Teaching among Thai second-year elementary student teachers			
	$\bar{X}$	S.D.	Meaning	rank
1. The integration of STEM education across all grade levels helps students acquire the essential knowledge and skills needed to effectively confront future challenges.	4.37	0.74	high	3
2. The use of STEM integration to create engaging and meaningful learning experiences for students.	4.22	0.80	high	11

(continued)

**Table 2 (continued)**

Items	The satisfaction with STEM integration through Micro-Teaching among Thai second-year elementary student teachers			
	$\bar{X}$	S.D.	Meaning	rank
3. The use of technology for the effective integration of STEM into teaching.	4.19	0.79	high	13
4. The integration of STEM in teaching enhances students' comprehension of science and technology	4.33	0.78	high	6
5. The use of various STEM-integrated learning activities	4.19	0.79	high	13
6. Accurate assessment of students' learning outcomes in STEM	3.96	0.65	high	19
7. Integrating STEM into teaching develops students' creativity and complex problem-solving skills.	4.30	0.78	high	8
8. The effective use of STEM learning activities helps students understand and identify the relationships between science, technology, engineering, and mathematics.	4.11	0.75	high	18
9. Integrating STEM education in teaching enables students to relate classroom knowledge to real-world contexts.	4.33	0.68	high	4
10. The integration of STEM into teaching increases students' interest in science.	4.33	0.73	high	5
11. Integrating STEM in teaching helps students better understand the content being taught.	4.30	0.78	high	8

(continued)

**Table 2 (continued)**

Items	The satisfaction with STEM integration through Micro-Teaching among Thai second-year elementary student teachers			
	$\bar{X}$	S.D.	Meaning	rank
12. The effective use of STEM integration to promote interdisciplinary learning in all subjects.	4.15	0.77	high	16
13. Employing real-life examples to facilitate students' understanding of STEM integration.	4.15	0.77	high	16
14. Integrating STEM in teaching helps students develop essential 21st-century skills.	4.26	0.81	high	10
15. The use of appropriate resources and tools for integrating STEM in teaching.	4.15	0.66	high	15
16. Integrating STEM in teaching promotes hands-on learning for students.	4.30	0.72	high	7
17. Developing appropriate STEM-integrated learning activities for various student groups.	3.96	0.71	high	20
18. Integrating STEM promotes student-centered learning.	4.44	0.70	high	1
19. Understanding STEM education through Micro-Teaching.	4.41	0.69	high	2
20. Overall, designing effective STEM-integrated learning activities and using appropriate instructional strategies was enabled by Micro-Teaching.	4.22	0.80	high	11
Total	4.23	0.75	high	

As can be seen in Table 2, the results revealed that the overall satisfaction with STEM integration through Micro-Teaching was at a high level ( $\bar{X}=4.23$ , S.D.=0.75). The item with the highest level and the highest average scores was 'integrating STEM promotes student-centered learning' ( $\bar{X}=4.44$ , S.D.=0.70). The item with the lowest level was 'developing appropriate STEM-integrated learning activities for various student groups' ( $\bar{X}=3.96$ , S.D.=0.71), respectively. The results implied that integrating STEM effectively fosters a student-centered learning environment, while there is room for improvement in tailoring STEM-integrated activities to different student groups. The findings are consistent with the previous studies (Rehmat, 2015; Gardner, 2017). The studies have shown that STEM integration through hands-on and interdisciplinary approaches enhances student engagement and learning. For instance, using real-world problem scenarios and engineering design challenges promotes critical thinking, problem-solving, and self-guided inquiry among students, which are essential components of a student-centered learning environment. Furthermore, the research indicates that the use of technology in STEM learning environments supports student learning by providing authentic contexts, facilitating web-based inquiry, and transforming students from consumers to creators.

The satisfaction with STEM integration through Micro-Teaching among Thai second-year elementary student teachers reveals several important insights. Table 2 presents detailed findings on various aspects of this integration, highlighting both strengths and areas for further improvement as follows.

**2.1 High Overall Satisfaction:** The overall satisfaction with STEM integration through Micro-Teaching is high,



with a mean score ( $\bar{X}$ ) of 4.23 and a standard deviation (S.D.) of 0.75. This indicates that elementary student teachers generally perceive the integration of STEM into their teaching practices positively, appreciating its benefits in enhancing educational experiences.

**2.2 Student-Centered Learning:** The highest satisfaction score ( $\bar{X}$  = 4.44, S.D. = 0.70) is for the item "Integrating STEM promotes student-centered learning," ranked first. This reflects a strong appreciation for how STEM integration encourages active learning, where students take charge of their learning process. This finding aligns with educational theories that emphasize the importance of student-centered approaches in fostering deeper understanding and engagement (Bransford, Brown, & Cocking, 2000).

**2.3 Understanding STEM through Micro-Teaching:** The second highest satisfaction score ( $\bar{X}$  = 4.41, S.D. = 0.69) is for "Understanding STEM education through Micro-Teaching." This indicates that the Micro-Teaching approach effectively helps elementary student teachers grasp the principles and applications of STEM education. Micro-Teaching provides a practical platform for teachers to refine their teaching strategies and improve their instructional skills (Allen & Ryan, 1969).

**2.4 Enhancing Interest and Real-World Relevance:** Items related to increasing students' interest in science ( $\bar{X}$  = 4.33, S.D. = 0.73) and enabling students to relate classroom knowledge to real-world contexts ( $\bar{X}$  = 4.33, S.D. = 0.68) both rank high. This suggests that integrating STEM in teaching not only captivates students' interest but also makes learning more relevant and applicable to their everyday lives. Real-world applications are essential in STEM education, as they help students see the value and utility of their learning (Honey, Pearson, & Schweingruber, 2014).

**2.5 Developing Critical Skills:** The integration of STEM in teaching to develop essential 21st-century skills, such as creativity and complex problem-solving ( $\bar{X}$  = 4.30, S.D. = 0.78), also received high ratings. This underscores the importance of STEM education in preparing students for future challenges by equipping them with the necessary skills. This is consistent with the goals of modern education, which emphasize preparing students for a rapidly changing world (National Research Council, 2012).

**2.6 Areas for Improvement:** Despite the overall high satisfaction, some areas need further improvement. For example, "Developing appropriate STEM-integrated learning activities for various student groups" received a lower satisfaction score ( $\bar{X}$  = 3.96, S.D. = 0.71). This indicates a need for more tailored and differentiated STEM activities that can address the diverse needs of different student groups. Differentiated instruction is crucial for meeting the varied learning needs and ensuring all students benefit from STEM education (Tomlinson, 2001).

**7. Effective Use of Resources and Tools:** The use of appropriate resources and tools for integrating STEM in teaching ( $\bar{X}$  = 4.15, S.D. = 0.66) suggests that while resources are effectively used, there is still room for enhancement. Providing teachers with better access to resources and training on how to use them can further improve STEM integration.

**8. Engaging and Meaningful Learning Experiences:** The satisfaction with creating engaging and meaningful learning experiences ( $\bar{X}$  = 4.22, S.D. = 0.80) indicates that STEM integration is seen as valuable in making learning more interactive and impactful. Engaging students through hands-on activities and real-life examples is a core component of effective STEM education (Blumenfeld, et al., 1991).



## 5. Conclusion and Implication

The findings of this study indicate that while the overall development of Technological Pedagogical Content Knowledge (TPCK) among second-year Thai elementary student teachers is high, specific areas such as Pedagogical Content Knowledge (PCK) and Technological Content Knowledge (TCK) require further enhancement. To ensure a well-rounded development of TPCK, future teacher education programs should focus on strengthening these components. By addressing these areas, teacher preparation programs can better equip future educators to effectively integrate STEM education and foster critical thinking and problem-solving skills in their students.

The high satisfaction levels reported by the student teachers suggest that STEM integration through Micro-Teaching is an effective approach for developing student teachers' skills and enhancing their teaching practices. However, there is a clear need to tailor activities to diverse student groups and to ensure the effective use of resources. By focusing on these areas, teacher education programs can further improve the quality and impact of STEM education.

The results underscore the importance of comprehensive teacher education programs that integrate technology, pedagogy, and content knowledge (TPCK). To effectively develop student teachers' TPCK for STEM integration, teacher preparation programs should incorporate a range of activities such as workshops, seminars, coaching, and mentoring. This holistic approach is essential for preparing teachers to create dynamic and interactive learning environments that foster student engagement and facilitate deeper learning.

## 6. Suggestion

(1) Develop tailored STEM-integrated activities that address the diverse learning needs and styles of various student groups.

(2) Explore the incorporation of emerging technologies such as virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) in STEM education.

(3) Conduct longitudinal studies to assess the long-term impact of STEM integration on student learning outcomes.

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