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Examining science teachers' TPACK impact on students' post-pandemic thinking skills

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ABSTRACT

The ability of science teachers to effectively integrate technology, teaching methods, and subject content knowledge, known as Technological Pedagogical Content Knowledge (TPACK), is vital in designing educational activities that enhance students' academic performance and their ability to think critically and creatively. This study investigates the level of TPACK proficiency among science teachers and its influence on students' advanced thinking skills. The research involved 124 science teachers from 76 schools in the northeastern region of Thailand. It assessed students' abilities in critical thinking, systems thinking, problem-solving, and creative thinking. The results show that nearly half of the science teachers (46.77%) have a moderate level of TPACK proficiency, categorized as the Exploring level. Additionally, the study found significant differences in students' thinking abilities based on the varying levels of TPACK expertise of their teachers. Therefore, there is an urgent need to develop and implement effective strategies for enhancing teachers' TPACK skills, with the goal of improving students' complex thinking skills.

1. Introduction

The repercussions of the global spread of COVID-19 have had substantial ramifications on the education system (UN, 2020). In the context of Thailand, measures have been instituted to enforce the closure of educational institutions, aiming to mitigate the dissemination of the virus. This closure has necessitated educational establishments and educators to strategically devise learning activities. Predominantly observed in the Thai educational landscape is the adoption of sophisticated teaching methodologies involving the creation of multimedia resources and the incorporation of diverse contemporary tools. These strategies facilitate the impartation of knowledge to students through various online learning formats utilizing educational technology. Certainly, it is evident that the aforementioned crisis has necessitated significant adaptation from both teachers and students. Teachers and students alike have had to engage in learning and acquire the understanding required to adapt to and comprehend various technologies. The resultant effect is that post-pandemic, various technologies have assumed a pivotal role in classroom management and learning (Addae et al., 2022; UNESCO, 2022). Both teachers and students have become more familiar with and recognize the importance of technology. Consequently, even after the major outbreak, there continues to be a substantial integration of technology in classrooms. However, studies indicate that in crisis-driven educational management, a phenomenon known as "learning loss" is observed, leading to increased educational disparities based on the readiness of learners and the capabilities of teachers in designing context-appropriate learning experiences. It is undeniable that if teachers can design teaching activities that appropriately integrate technology. This efficiency in learning design can lead to improved learning outcomes and the effective development of students' cognitive abilities. Conversely, if teachers are unable to design suitable activities or design them inadequately for the context, they may not be able to develop students' potential effectively.Therefore, it can be stated that incorporating technology into teaching methods facilitates seamless learning for students; nonetheless, its effective implementation is typically contingent on the technological and pedagogical capabilities of educators. Numerous research endeavors have underscored the significance of these competencies and the expertise of teachers in instructional practices (Oliva-Cordova et al., 2021). Consequently, it can be said that a crucial factor influencing contemporary student learning is the integration of content knowledge, instructional methods, and technology, often referred to as Technological Pedagogical Content Knowledge (TPACK). TPACK is built on Shulman's description (Shulman, 1987): T for technology, P for pedagogy, C for content, and K for knowledge. It acts as a platform that combines three main areas of knowledge that interact in a cyclical fashion. TPACK, as conceptualized by Mishra and Koehler (2006), serves as a holistic framework that bridges technological proficiency, pedagogical acumen, and content knowledge. It posits that effective technology integration is contingent on educators possessing a nuanced understanding of how these domains intersect, creating a unique amalgamation that propels meaningful learning experiences.

Competence in thinking is a crucial attribute for individuals in the current era who must navigate the rapidly changing, dynamic, unpredictable world of the 21st century (Panich, 2017). Therefore, educational administration tasked with preparing individuals for these dynamic changes must recognize the significance of fully developing students' capabilities. This ensures that the emerging generation is equipped with the necessary high-level skills for learning and adapting, enabling them to stay abreast of economic transformations towards increased self-reliance and evolving learning environments. This encompasses the substantial impact of learning outcomes and, notably, the cultivation of elevated thinking competency. Thinking competency, a range of cognitive abilities, empowers individuals to analyze information, evaluate evidence, formulate arguments, solve problems, think creatively, and make sound decisions (NEA, 2012). This set of cognitive skills proves indispensable for achievement in academia, professional endeavors, and overall life success. Within educational settings, thinking competency facilitates students' acquisition and comprehension of new information while aiding in problem-solving and decision-making. In the professional realm, proficiency in thinking is a linchpin for success across diverse occupations. Moreover, it is also important for personal development, as it helps individuals make informed decisions about their lives (Pascarella and Terenzini, 2005). In practical terms, this synergy manifests in lesson designs that leverage technology to cultivate thinking competency. Incorporating interactive simulations, multimedia resources, and collaborative online platforms becomes not just about technology integration but a strategic means to enhance thinking competency. Educators armed with TPACK can curate digital content that stimulates analytical thinking and creative exploration. A substantial body of research indicates that the purposeful integration of TPACK within learning design frameworks demonstrates a statistically significant positive correlation with student achievement. Empirical studies further suggest that implementing TPACK principles in instructional design has a demonstrably positive impact on learning outcomes, fostering the development of essential cognitive skills in learners, such as critical thinking, problem-solving, and creative thinking (Handan and Ertuğrul, 2019; Rahman et al., 2023; Septiandari, 2020; Sulistyarini et al., 2022).

Therefore, the primary objective of this work is to fill in the gaps in teachers' TPACK and their influence on students in science classrooms. It aims to answer the question of how the levels of TPACK usage by science teachers impact high school students' thinking competency. This will lead to a clearer understanding and effective planning and design of teacher development strategies in the post-major educational disruption era. For educators, the integration of TPACK and thinking competency necessitates targeted professional development. Workshops and training programs should focus not only on technological tools but also on strategies that harness these tools to stimulate higher-order thinking skills. This holistic approach empowers educators to become adept facilitators of knowledge construction in the digital age.

2. Related literature

2.1. TPACK

In today's rapidly evolving digital landscape, the integration of technology into the teaching and learning process has become increasingly crucial; the TPACK framework, introduced by Mishra and Koehler (2006), has emerged as a prominent tool for comprehending and cultivating the knowledge and skills necessary for educators to effectively employ technology in classrooms, encompassing technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK), along with four knowledge intersections: TPCK, TPK, PCK, and CK; Technological Knowledge (TK) involves the understanding and application of technology tools and resources in education, including familiarity with hardware and software tools, troubleshooting technological issues, and adapting to emerging technologies; Pedagogical Knowledge (PK) pertains to the understanding of effective teaching and learning strategies, encompassing various pedagogical approaches and the ability to design and implement engaging and effective learning experiences; Content Knowledge (CK) refers to a deep understanding of the subject matter taught, including mastery of concepts, theories, and principles, and the ability to connect subject matter to real-world applications; TPACK, the central component, represents the intersection of TK, PK, and CK, involving the ability to use technology to enhance teaching and learning in a specific subject area; TPK represents the intersection of TK and PK, involving the understanding of how technology can be used to implement various teaching and learning strategies; PCK refers to the intersection of PK and CK, involving the understanding of how to effectively teach a specific subject matter; CK represents the intersection of CK and TK, involving the understanding of how technology can be used to enhance the teaching and learning of a specific subject matter; the TPACK framework has been widely applied in various educational settings, demonstrating its effectiveness in enhancing teacher preparation and professional development, improving technological fluency, pedagogical practices, and content knowledge, ultimately leading to improved student learning outcomes; as technology continues to evolve and play an increasingly prominent role in education, the TPACK framework will remain a critical guide for preparing educators to navigate the digital landscape and enhance student learning.

2.2. Thinking competency

Thinking competence is a comprehensive characteristic of a person's ability to integrate knowledge, skills, and other characteristics to think, analyze, synthesize, and make decisions critically on the basis of reason in a comprehensive manner. It uses morality to guide decisions in a critical manner. It has the ability to think logically with an understanding of the interconnectedness of things that coexist in a systematic way. It uses imagination and knowledge to create new alternatives to solve complex problems. Critical thinking (CT) is a cognitive skill set characterized by deliberate and rational contemplation, essential for forming judgments and decisions. It employs a range of techniques and methodologies to enhance the probability of sound decision-making. These competencies encompass the interpretation, evaluation, analysis, summarization, and explication of evidence, concepts, methods, rules, or contextual factors extracted from observed data, personal experiences, reasoning, reflection, communication, and argumentation (Ennis, 1985). Watson and Glaser (1964) determined that the comprehensive assessment of critical thinking ability requires an evaluation of specific sub-skills. These sub-skills encompass the measurement of one's capacity for inference, involving the ability to make categorical judgments about the likelihood of a conclusion being true or false. Additionally, the assessment includes the recognition of assumptions, gauging an individual's ability to discern whether a provided statement constitutes an assumption. Deductive reasoning is another crucial sub-skill evaluated, focusing on the individual's capacity to draw logical conclusions from given premises using principles of logic. Furthermore, the evaluation encompasses interpretation ability, measuring proficiency in weighing information and evidence to judge the plausibility of a conclusion. Lastly, the assessment evaluates the ability to discern and assess the rational use of reasoning, determining what is considered logically sound in the context of argumentation. System thinking (ST) signifies a cognitive paradigm that delves into the interdependence of constituent elements within the comprehensive context of an environmental setting where a problem is situated. Going beyond superficial occurrences, it discerns patterns, behavioral trends, and underlying determinants, fostering an in-depth comprehension of systemic situations and facilitating the resolution of foundational issues (Senge, 1990). According to Kim (1999), the hierarchy of cognitive processes, often elucidated through the metaphor of an iceberg, delineates four discernible strata. Firstly, at the apex is the event level—the realm of immediate perceptual experiences, exemplified by quotidian occurrences such as waking up with a cold. While ostensibly amenable to facile rectification through surface-level adjustments, the iceberg model serves as a cautionary reminder against premature assumptions that all predicaments yield to symptomatic or event-level interventions. Directly beneath this veneer resides the pattern level, where the discernment of recurring temporal configurations unveils predictive capacities. Notably, the ability to identify patterns, such as a heightened susceptibility to illness in the context of insufficient rest, confers a proactive stance in anticipating and forestalling future manifestations. Descending further into the cognitive stratum, we encounter the structure level, characterized by an interrogation into the causal underpinnings of observed patterns. Here, elucidating the structural determinants contributing to, for instance, the recurrent manifestation of colds involves an exploration of multifaceted factors. These may encompass heightened workplace stress precipitated by novel promotion policies, habitual maladaptive dietary responses to stress, or the suboptimal accessibility of healthful sustenance. Notably, this includes physical entities, organizational frameworks, policy architectures, and ingrained ritualistic behaviors within the purview of cognitive structures. Conclusively, the model culminates in the mental model level—the substratum where latent assumptions, attitudes, beliefs, and values, often assimilated subconsciously from societal or familial influences, exert profound influence. Within this cognitive stratum, nuanced beliefs regarding the significance of career to personal identity, perceived economic barriers to access to healthful sustenance, or culturally ingrained notions about the role of rest may operate as imperceptible yet potent determinants shaping susceptibility to afflictions such as the common cold. Creative thinking (CT) is a cognitive process characterized by diversity, innovation, evaluation, refinement, and development of ideas aimed at effective problem-solving, alternative generation, and the advancement of knowledge or creative expression. Rooted in imagination and fundamental thinking skills like initiative, fluency, flexibility, thoroughness, diversity, analysis, and synthesis, creative thinking aspires to yield original, valuable, and useful outcomes for oneself, others, and society. The characteristics inherent in creative thinking should encompass three fundamental elements. Firstly, there is the element of novelty, emphasizing the generation of ideas that deviate from existing thought frameworks. This involves introducing concepts that have not previously been contemplated, even by the thinkers themselves. Secondly, creative thinking entails workability, extending beyond mere imaginative ideation. It is characterized by the ability to transform ideas into tangible and practical outcomes, aligning with the objectives of the thought process. Lastly, appropriateness is a crucial dimension, signifying thinking that adheres to a sense of causality. This type of thinking is deemed suitable and valuable based on widely accepted standards and norms. Guilford's (1968) delineation of divergent thinking characteristics encompassed four distinct attributes. Firstly, fluency denotes the ability to generate a myriad of responses to a stimulus within a constrained time frame, emphasizing the quantitative aspects of thinking. It is the brain's adeptness at swiftly producing answers in response to a stimulus. This type of thinking can be further categorized into verbal fluency, associational fluency, expressional fluency, and ideational fluency, each involving the facile use of words or generation of related concepts within specified time frames. Secondly, flexibility pertains to an individual's capacity to think of answers in various types and directions, enriching divergent thinking by categorizing or classifying thoughts. This includes spontaneous flexibility, freely attempting to think in multiple directions, adapter flexibility, and the modification of knowledge or experiences for diverse problem-solving applications. Thirdly, originality signifies the cognitive ability to provide answers that are distinctive, deviating from conventional thinking and avoiding duplication by others. Lastly, elaboration involves thinking in detail to embellish or expand the main idea, making it more comprehensive. A proficient creative thinker must extract the essence of an idea, branching out thoughts in every direction, developing and expanding branches, and refining details around the original thought. Elaboration is the intricate process of detailing that enables a clear description or a comprehensive plan, enhancing and completing the initial thought. Problem-solving thinking (PST) encapsulates the cognitive facets involved in problem identification, definition, data collection, method design, option selection, and effective resolution. It adheres to clear and comprehensive criteria across all dimensions to systematically address and solve problems, ensuring a methodical and thorough approach to problem-solving processes.

Weir (1974) delineated a comprehensive four-step problem-solving methodology. The initial step involves the identification of the problem, accomplished by describing the unsatisfactory or altered situation in the environment, thereby recognizing factual elements within the given scenario that may pose a threat. Progressing to the second step, a detailed analysis of the problem is undertaken to unveil its genuine causes, necessitating a profound comprehension of the factors contributing to the unsatisfactory or changed situation, aligned with the provided information. Subsequently, the third step revolves around proposing a solution, entailing the discovery of a problem-solving method in harmony with the identified causes, aiming for a rational and effective resolution to the unsatisfactory or changed environmental scenario. The conclusive step centers on the evaluation of the problem-solving results, encompassing the elucidation of outcomes, an assessment of their coherence with the initial situation, and a determination of the efficacy of the problem-solving process in addressing the unsatisfactory or altered environment.

3. Methodology

The purpose of this study is to investigate the TPACK levels of science teachers and the thinking competency of students taught by science teachers with different levels of TPACK. This investigation involves a survey-based research approach, utilizing questionnaires for science teachers and assessments to measure students' thinking competency.

3.1. Research participants

The study's population comprises science teachers within secondary schools in the northeastern region of Thailand for the academic year 2022-2023, spanning 20 provinces and totaling 458 schools. The determination of the sample size is conducted through the application of Taro Yamane's formula, accounting for a 95% confidence level and an approximate margin of error of ±5% (Yamane, 1967). In the context of sample group randomization, stratification by provinces is executed, guided by Taro Yamane's formula, wherein the enumeration of schools in each province is a crucial factor, as delineated in Table 1. Subsequently, a stratified random sampling methodology is applied, incorporating school size as a criterion, thereby classifying establishments into large, medium, and small dimensions within each province. This meticulous categorization aims to achieve a comprehensive representation. Following the ascertainment of school quantities in each size classification and province, the selection process adheres to a randomization protocol, optimizing for convenience and logistical efficiency. A convenient sampling approach is used to gather data from science teachers. This involves obtaining information from 124 teachers in 76 schools. Additionally, a purposive sampling method is employed to select a sample of students studying science under the purview of the selected science teachers.

Table 1: Population and sample

Province	Population	Sample	Province	Population	Sample
Khon Kaen	84	4	Maha Sarakham	35	4
RoiEt	60	4	Loei	34	4
Nakhon Phanom	51	4	Udon Thani	63	4
Sakon Nakhon	45	4	Nong Khai	31	4
Nongbua Lumphu	21	3	Mukdahan	30	4
Bueng Kan	25	3	Chaiyaphum	37	4
Sisaket	56	4	Burirum	67	4
Surin	85	4	Yasothon	27	3
Amnat Charoen	22	3	Kalasin	55	4
Nakhon Ratchasima	50	4	Ubon Ratchathani	59	4
Total	Population=458			Sample=76	

3.2. Research instruments

1. The TPACK Questionnaire, adapted from Schmidt et al. (2009), is constructed utilizing a 5-point rating scale. This survey evaluates all seven facets of TPACK, encompassing Technological Knowledge (TK), Content Knowledge (CK), Pedagogical Knowledge (PK), Pedagogical Content Knowledge (PCK), Technology Content Knowledge (TCK), Technology Pedagogical Knowledge (TPK), and TPACK. Each dimension comprises four items. The experts confirm a content validity of 0.95 for the questionnaire, with item appropriateness scores ranging from 4.88 to 5.00.
2. A thinking competency test, composed of four sets of cognitive assessments, includes:

   a. Critical thinking measurement: A situational multiple-choice test with 4 options comprising 6 scenarios. It is based on Quellmalz (1985), modified from Ennis's (1985) critical thinking framework, which includes four categories: Problem definition, data analysis, summarization, and reference. The index of congruence between the questions and the measured behaviors is 1.00. Item discrimination ranges from 0.26 to 0.68, and the difficulty level ranges from 0.28 to 0.67. The reliability coefficient is 0.86.
   b. Systems thinking measurement: A situational multiple-choice test with 4 options encompassing 4 scenarios. It is based on Kim's (1999) systems thinking framework, which includes four levels of thinking: Event, pattern, structure, and mental model. The index of congruence between the questions and the measured behaviors is 0.90. Item discrimination ranges from 0.21 to 0.78, and the difficulty level ranges from 0.28 to 0.79. The reliability coefficient is 0.82.
   c. Problem-solving measurement: A situational multiple-choice test with 4 options, consisting of 5 scenarios (20 items). The problem-solving assessment is based on Weir's (1974) problem-solving framework, which consists of four steps: Problem identification, problem analysis, proposing solutions, and evaluating results. The index of congruence between the questions and the measured behaviors is 1.00. The item discrimination ranges from 0.21 to 0.82, and the difficulty level ranges from 0.23 to 0.79. The reliability coefficient is 0.87.
   d. Creative thinking measurement: The creative thinking assessment, in the form of open-ended questions, consists of 2 scenarios. It is based on Guilford's (1968) creative thinking framework, which includes four dimensions: Fluency, flexibility, originality, and elaboration. The index of congruence between the questions and the measured behaviors is 0.95. Item discrimination ranges from 0.41 to 0.76, and the difficulty level ranges from 0.24 to 0.76. The reliability coefficient is 0.89.

3.3. Data collection and analysis

The purpose of this study is to collect data on science teachers' TPACK after the pandemic. The researcher received ethical approval from the Human Research Ethics Committee at Mahasarakham University. To obtain data on TPACK, the researchers contacted selected participants, requested their cooperation, provided detailed instructions, and asked them to fill out a questionnaire via Google Forms. Additionally, teachers were required to help coordinate assessments of thinking skills with their students in science classes. After collecting the data, the researchers analyzed it.

The information obtained from the survey, which aimed to evaluate the TPACK proficiency of science teachers, was analyzed using the mean and standard deviation (S.D.). The interpretation of these statistical measures adapts from the guidelines established by Lee et al. (2006) as:

- 4.21–5.00 means the level of advancing; eagerly considers using TPACK in a variety of ways in building concepts-encourages student hands-on explorations andexperimentation, incorporates TPACK in student assessment
- 3.41–4.20 means the level of exploring; examines different ways of teaching mathematics content - willing to demonstrate new ways of thinking about concepts with TPACK, able to manage the classroom and carefully guide students toward gaining the concept.
- 2.61–3.40 means the level of adapting; tries ideas for incorporating TPACK in teaching, but in teaching students, at best, students use drills and practice the ideas withthe TPACK.

- 1.81–2.60 means the level of accepting practices using differentcapabilities of teacher knowledge but not a consistent thought
- 1.00–1.80 means the level of recognizing; Recognizes all seven aspects of TPACK but rarely thinks about incorporatingthis knowledge.
- Regarding the analysis of data from the thinking tests, the researchers score and analyze the results using one-way analysis of variance (ANOVA).

4. Results

4.1. The level of science teachers' TPACK

The results of the basic data analysis of science teachers in the sample group are shown in Table 2. Through data analysis, it has been determined that the TPACK proficiency levels among science teachers are as follows: 45 individuals are categorized at the 'Advancing' level, 58 individuals at the 'Exploring' level, and 17 individuals at the 'Adapting' level. Additionally, there are 2 individuals each at the 'Accepting' and 'Recognizing' levels. These findings can be extrapolated into percentages, and a visual representation is depicted in Fig. 1. The information in Fig. 1 indicates that a significant portion of science teachers, at 46.78%, possess a TPACK level categorized as "Exploring." Subsequently, 36.29% fall into the "Advancing" level, while 13.71% are classified under the "Adapting" level. Furthermore, both the "Accepting" and "Recognizing" levels share an equal representation at 1.61%.

4.2. The impact of diverse TPACK levels on students' thinking competency

Based on the examination of the thinking competency of the students, who are taught by science teachers with different levels of TPACK, variations in thinking competency scores are identified. The specifics are outlined as shown in Table 3.

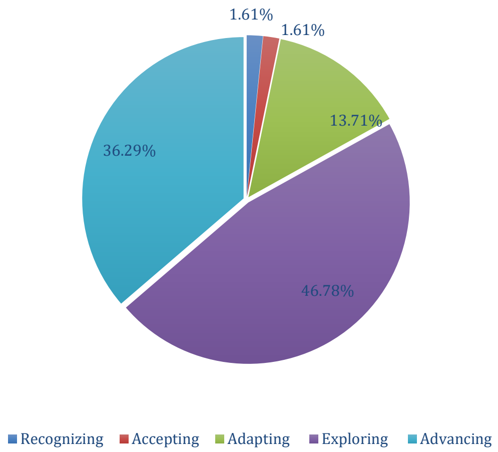

Fig. 1: Percentage of teachers' TPACK level

Table 2: The basic data analysis of science teachers

Items		Frequency	Percentage
Gender	Male	39	31.45
	Female	85	68.55
total		124	100
Teaching experience	< 2 years	33	26.61
	3-5 years	26	20.97
	6-8 years	20	16.13
	> 8 years	45	36.29
total		124	100
The instructional level	Lower secondary school	53	42.74
	Higher secondary school	71	57.26
	total	124	100

Table 3: Students' thinking competencies categorized based on the TPACK levels of science teachers

Thinking competency	Level of TPACK	N	Full score	$\bar{X}$	SD	df	F	P
Critical thinking	Recognizing	1337	20	7.08	1.70	4	3.171**	0.019
	Accepting			7.01	0.17			
	Adapting			9.46	2.13			
	Exploring			10.08	1.57			
	Advancing			10.09	1.51			
System thinking	Recognizing	1314	20	10.40	0.18	4	5.724**	0.001
	Accepting			7.02	0.61			
	Adapting			9.50	1.50			
	Exploring			10.94	1.37			
	Advancing			10.12	1.60			
Problem-solving	Recognizing	1688	24	13.10	.001	4	20.46**	0.000
	Accepting			12.38	1.10			
	Adapting			15.03	1.36			
	Exploring			16.78	1.44			
	Advancing			17.46	0.81			
Creative thinking	Recognizing	1681	20	6.87	0.07	4	40.65**	0.000
	Accepting			7.03	0.38			
	Adapting			7.37	0.49			
	Exploring			8.56	0.49			
	Advancing			8.90	0.39			

**: p<0.05

From Table 3, it is evident that science teachers with different levels of TPACK have an impact on students' thinking competencies, with statistical significance at the 0.05 level. The present study revealed a significant effect of varying teacher TPACK levels on students' thinking competency, manifested in differential outcomes across critical thinking, systems thinking, problem-solving, and creative thinking domains.

Following that, a pairwise comparative study is conducted to investigate which TPACK levels differed in terms of each aspect of thinking competency. The details are as follows:

- Critical thinking: Following the initial analysis of variance (ANOVA) revealing a significant influence of teacher TPACK levels on student critical thinking, a pairwise comparison study was conducted. This study investigates the differences in critical thinking among students grouped by their teachers' TPACK levels. The analysis results are presented in Table 4.

Table 4: Comparing the critical thinking scores of students categorized according to the TPACK levels of science teachers when classified into pairs (n=1314)

Level of TPACK	X̄	Recognizing	Accepting	Adapting	Exploring	Advancing
Recognizing	7.08	-	0.073	-2.37	-2.99**	-3.01**
Accepting	7.01			-2.45	-3.07**	-3.08**
Adapting	9.46				-0.62	-0.64
Exploring	10.08					-0.013
Advancing	10.09					-

**: p<0.05

When comparing the critical thinking of students categorized according to the TPACK levels of their science teachers, it is found that there are significant differences in students' critical thinking skills. This is statistically evident at the 0.05 significance level, with a total of 4 pairs, namely: 1) the Recognizing and Exploring level group, 2) the Recognizing and Advancing level group, 3) the Accepting and Exploring level group, and 4) the Accepting and Advancing level group.

- Systems thinking: As the preliminary analysis of the ANOVA data, it has been observed that varying levels of TPACK among teachers influence students' systems thinking differently. Consequently, a comparative study has been conducted to assess the systems thinking of students, categorized based on the TPACK levels of their respective teachers on a paired basis. The analytical results align with the findings presented in Table 5.

Table 5: Comparing the systems thinking scores of students categorized according to the TPACK levels of science teachers when classified into pairs (n=1337)

Level of TPACK	X̄	Recognizing	Accepting	Adapting	Exploring	Advancing
Recognizing	10.40	-	3.38	0.90	-0.53	-0.49
Accepting	7.02			-2.48	-3.91**	-2.89
Adapting	9.50				-1.43**	0.41
Exploring	10.94					-1.03
Advancing	10.12					-

**: p<0.05

When comparing students' systems thinking categorized by the TPACK levels of their teachers, it is found that students exhibit different abilities in systems thinking. This is statistically significant at the 0.05 significance level, with a total of 2 pairs, namely: 1) the Accepting level and the Exploring level group, and 2) the Adapting level and the Exploring level group.

- Problem-solving: Following the initial ANOVA revealing a significant influence of teacher TPACK levels on student problem-solving skills, a pairwise comparison study is conducted. This study investigated the differences in problem-solving abilities among students grouped by their teachers' TPACK levels. The analysis results are presented in Table 6.

Table 6: Comparing the problem-solving scores of students categorized according to the TPACK levels of science teachers when classified into pairs (n=1688)

Level of TPACK	X̄	Recognizing	Accepting	Adapting	Exploring	Advancing
Recognizing	13.10	-	0.71	-1.92	-3.68**	-4.36**
Accepting	12.38			-2.64	-4.39**	-5.07**
Adapting	15.03				-1.75**	-2.43**
Exploring	16.78					-0.68
Advancing	17.46					-

**: p<0.05

When comparing students' problem-solving categories by the TPACK levels of their teachers, it is found that students possess different abilities in problem-solving. This difference is statistically significant at the 0.05 significance level, with a total of 6 pairs, namely: 1) the Recognizing level and the Exploring level group, 2) the Recognizing level and the Advancing level group, 3) the Accepting level and the Exploring level group, 4) the Accepting level and the Advancing level group, 5) the Adapting level and the Exploring level group, and 6) the Adapting level and the Advancing level group.

- Creative thinking: Based on preliminary analysis of the ANOVA data, it is evident that varying levels of TPACK among teachers have an impact on students' creative thinking. Consequently, a study has been conducted to compare the creative thinking of students categorized according to the TPACK levels of their respective teachers on a paired basis. The analytical outcomes align with the findings presented in Table 7.

Table 7: Comparing the creative thinking scores of students categorized according to the TPACK levels of science teachers when classified into pairs (n=1681)

Level of TPACK	$\bar{X}$	Recognizing	Accepting	Adapting	Exploring	Advancing
Recognizing	6.87	-	-0.16	-0.50	-1.69**	-2.03**
Accepting	7.03			-0.34	-1.53**	-1.87**
Adapting	7.37				-1.18**	-1.52**
Exploring	8.56					-0.34
Advancing	8.90					-

**: p<0.05

When comparing students' creative thinking categorized by the TPACK levels of their teachers, it was found that students possess different abilities in creative thinking. This difference is statistically significant at the 0.05 significance level, with a total of 6 pairs, namely: 1) the Recognizing level and the Exploring level group, 2) the Recognizing level and the Advancing level group, 3) the Accepting level and the Exploring level group, 4) the Accepting level and the Advancing level group, 5) the Adapting level and the Exploring level group, and 6) the Adapting level and the Advancing level group.

5. Discussion

The investigation into the proficiency levels of TPACK among high school science teachers in the northeastern region of Thailand indicates a predominant utilization of the Exploring level within the TPACK framework, with 46.77%. Subsequently, the Advancing level is observed at 36.29%, followed by the Adapting level at 13.71%. Notably, the least represented levels are Accepting and Recognizing, each accounting for 1.61%. This study illuminates the transformative impact of the COVID-19 pandemic on educators, particularly in fostering an environment where teachers have actively sought to acquire proficiency in applying technology to pedagogy.

The results underscore a commendable inclination towards technological exploration and advancement among science teachers. Notably, the majority operate within the Exploring and Advancing levels of TPACK, signaling a proactive embrace of technology to enrich teaching methodologies. This heightened awareness is accompanied by a discerning understanding among teachers that judiciously integrating technology into instructional frameworks can significantly augment the efficacy of student learning. The findings further reveal a strategic foresight among educators, as evidenced by their intent to systematically embed technology in forthcoming pedagogical endeavors (Niess et al., 2007). This forward-thinking approach aligns with contemporary educational paradigms emphasizing the thoughtful integration of technology for enhanced learning outcomes. Notably, the Accepting and Recognizing levels, each accounting for 1.61%, emerge as the least represented categories. This indicates a smaller percentage of teachers at the foundational stages of TPACK development. Teachers in these categories may be in the early stages of acknowledging the significance of technology in education and gradually accepting its integration into their teaching practices.

Amidst the global COVID-19 pandemic, teachers found themselves necessitated to adeptly incorporate technology into their pedagogical approaches. This period of heightened reliance on technology served as an impetus for teachers to engage in continuous professional development, acquiring valuable insights and experiences in the synergistic integration of technology within the educational landscape. This deliberate effort aimed to address contextual challenges and intricacies inherent in their teaching environments. Subsequently, as teachers immersed themselves in frequent and purposeful technology use, a discernible shift occurred in their attitudes, marked by an increased acknowledgment and appreciation of the advantages associated with technology utilization.

This transformative experience fostered a positive perspective and a proactive stance toward the adoption of technology. The resultant paradigm shift has not only instilled a greater acceptance of technology but has also set the stage for the judicious application of technology across diverse educational domains (Hussein, 2017; Songkram et al., 2023; Svenningsson et al., 2022). Furthermore, upon witnessing the outcomes and benefits derived from utilizing technology in educational management, both in terms of enhanced personal convenience as a facilitative and stimulating learning resource and in fostering effective student learning, there arises a palpable acceptance and recognition of the value of technology. This, in turn, instills a readiness to apply technology in designing future instructional strategies. This development significantly contributes to the concurrent enhancement of teachers' TPACK.

These findings align with the research conducted by Akram et al. (2021) and Chang et al. (2015), underscoring the correlation between teachers' TPACK and their experiences in instructional management. The increased and effective application of TPACK is shown to deepen understanding, facilitate continuous learning, and foster the progressive development of TPACK.

Differences in science teachers' TPACK levels result in variations in students' thinking competencies at a statistically significant level of 0.05. thinking categories reveal a broad alignment in their respective trajectories. However, a more granular analysis through pairwise comparisons exposes a distinctive pattern, particularly within the pairs associated with varying student thinking competencies. When considering each type of thinking individually, it is found that they align in the same direction. Upon evaluating the average scores of thinking abilities, these two tiers exhibit markedly higher performance compared to their counterparts. This discernible divergence suggests that the pedagogical approaches undertaken by science teachers possessing differing TPACK levels significantly impact students' cognitive engagement, particularly in the domains of exploration and advancement.

The study's findings demonstrate a statistically significant relationship between science teachers' TPACK levels and students' thinking competencies. Teachers with higher TPACK levels were found to have students who performed better across all thinking categories, with particularly notable differences in the domains of exploration and advancement. This suggests that the pedagogical approaches employed by teachers with strong TPACK skills can effectively foster students' cognitive engagement and higher-order thinking abilities.

Nurtjahyani et al. (2022) indicated that the acquisition of TPACK has the potential to enhance creativity and critical thinking skills among students, with a particular focus on improving their abilities in identification, connection, analysis, and conclusion. The effectiveness of incorporating TPACK learning methodologies in the context of science education was evident in the positive impact observed on students' critical thinking abilities. This is according to research conducted by Wardani and Jatmiko (2021), which indicated that TPACK-based physics learning with the PBL model is effective in enhancing students' critical thinking skills. In addition to the fact that having a high level of TPACK can assist teachers in designing learning experiences that effectively promote thinking competence, it may also contribute to increasing teachers' confidence in teaching.

According to Novita et al. (2022), the skills of using technology in learning related to TPACK had a positive effect on increasing teacher confidence and their confidence in designing lessons. However, it is notable that the sole exception to this trend lies within the realm of systems thinking. Here, the higher score is localized within the Exploring level, distinguishing it from other thinking abilities. This distinctiveness underscores the unique impact of TPACK variances on the cultivation of system thinking skills among students. In interpreting these findings, it is imperative to recognize the multifaceted nature of TPACK and its differential influence on diverse facets of students' thinking competencies. The prominence of Exploring and Advancing levels further underscores the pedagogical importance of tailoring instructional strategies to align with the nuanced demands of these cognitive domains. The nature of systems thinking involves understanding complex relationships and feedback loops within a system (Senge, 1990).

Explaining these concepts in a way that is accessible to students, especially those at different age and cognitive levels, can be challenging for teachers. Therefore, system thinking may require a different pedagogical approach than other thinking abilities, one that emphasizes exploration and discovery rather than direct instruction, which teachers may not be familiar with. Moreover, Systems thinking often requires an interdisciplinary approach, drawing on concepts from various subjects. Integrating these diverse ideas into a cohesive curriculum can be challenging, as it may require collaboration among teachers from different disciplines.

6. Conclusions and recommendations

It can be seen that teachers' TPACK is related to the thinking competency of students. Therefore, in the development of teacher competencies, TPACK should be continuously developed. The implementation of professional development, for instance, community of practice and lesson study, represents a crucial means to enhance teachers' TPACK. Participation in communities of practice facilitates the exchange of insights and experiences, refining pedagogical approaches and fostering a comprehensive understanding of technology integration. Concurrently, the structured nature of lesson study creates collaborative planning, observation, and reflective practices, seamlessly incorporating digital tools into their teaching. These initiatives collectively contribute to the cultivation of TPACK, ensuring teachers remain adept in navigating the evolving landscape of educational technology through a culture of collaborative learning and inquiry.

However, this study has been confined to the Northeast of Thailand. It is advisable that further research be undertaken in other regions to enhance the comprehensiveness of the findings and provide a more distinct overall perspective. In addition, the information obtained is only basic data, so it is necessary to study the information comprehensively, considering opposition from various perspectives, including the learners' context, schools, or studying the specific pedagogical methodologies that contribute to the observed disparities, shedding light on effective instructional practices for enhancing students' thinking competency in science education.

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Compliance with ethical standards

Ethical consideration

This study was conducted in accordance with the ethical standards of Mahasarakham University and the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study. Each participant was informed about the purpose of the research, the procedures used, potential risks, and their rights to confidentiality and withdrawal from the study without any penalty. Written consent was obtained prior to participation.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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