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Exploring the interplay between students' scientific competence and teaching instructors' TPACK: A comprehensive analysis

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Abstract

This exploratory research investigates the scientific competence levels among secondary school students in the North Eastern region of Thailand in the post-COVID-19 era and examines the relationship between teachers' Technological Pedagogical Content Knowledge (TPACK) and students' scientific competency. The study collects data from 76 science teachers and 1878 students representing 76 schools in the northeast of Thailand. The study employs a set of instruments, including 1) the 28 items of the TPACK questionnaire and 2) the scientific competency measurement tool. The findings reveal that the overall scientific competency score among students reflects a moderate level. Specifically, students demonstrated moderate competence in "explaining phenomena scientifically" and "evaluating and designing scientific inquiry," while their ability to "interpret evidence and data scientifically" was found to be at a low level. Furthermore, there is a significant but low-level correlation between the scientific competency of students and the TPACK of their teachers. The findings highlight the urgent need for a pedagogical shift in educational practices. There is a pressing need to design learning experiences that emphasize scientific inquiry and critical thinking rather than focusing solely on subject matter expertise. Strengthening teachers' capacity to integrate technology with pedagogy alongside fostering inquiry-based learning approaches will be crucial in improving students' scientific competencies and preparing them to handle challenging problems in the contemporary world.

Keywords: Professional development, Scientific competency, Teacher education, TPACK, Teacher competency, Science teacher.

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1. Introduction

The dawn of the 21st century heralds an era marked by unprecedented technological strides, globalization and an array of complex challenges that transcend geographical boundaries. In this dynamic and intricate landscape, the acquisition of scientific competency emerges as a paramount skill, transcending traditional confines to become an imperative for individuals across diverse fields. Scientific competence goes beyond factual knowledge, encompassing critical thinking, problem-solving, communication, teamwork and adaptability skills essential for navigating today's rapidly changing world. A scientifically literate population is not only better equipped to make informed decisions, engage in discussions on scientific issues and support sustainable practices but also plays a crucial role in fostering innovation to tackle global challenges. These competencies enable individuals and societies to distinguish fact from misinformation, adapt to new developments and contribute to the well-being of society as a whole. However, scientific competency remains unevenly distributed across populations due to a variety of reasons including financial level, educational access and cultural differences despite its significance [1].

Within this context, teachers are empowered by the Technological Pedagogical Content Knowledge (TPACK) framework to effectively incorporate technology into subject-specific instruction especially in science education. TPACK is a key framework that influences how teachers use technology in science lessons. TPACK encompasses the subtle interplay of technology, pedagogy, and content knowledge—a unique blend of abilities that allows teachers to smoothly integrate technology into their science teachings [2]. The teachers with higher levels of TPACK are skilled at creating compelling and dynamic learning environments [3]. These environments promote a deeper understanding of scientific concepts, resulting in improved science learning outcomes among students. Effective TPACK integration helps teachers blend technology with their teaching strategies and subject knowledge to create engaging and interactive learning experiences. Teachers can facilitate a more dynamic and inquiry-based approach to learning by using technology to convey science concepts. This allows students to explore scientific principles through hands-on investigations, experimentation, and data analysis fostering deeper understanding. Technology enhances these processes, enabling students to refine essential skills like critical thinking and problem-solving as they actively engage with scientific content. Furthermore, TPACK increases students' teamwork and communication skills. Technology offers collaborative learning experiences in which students cooperate on projects, discuss ideas, and engage in scientific conversation. These collaboratives establish vital communication skills and teamwork attributes integral not only to success in science but also in other domains of life.

This study investigates the significance of scientific competency and TPACK in science education. We aim to deepen our understanding of how teachers may effectively promote scientific literacy and competency in an increasingly digital and interconnected society by studying the relationship between these two concepts. This study shed light on the consequences of this link for educational practice and policy eventually improving the quality and efficacy of science education in the classroom.

2. Literature Review

2.1. Scientific Competency

Scientific competency is a multidimensional construct necessary for success in scientific inquiry, research, and practice [4]. It entails a wide range of skills, knowledge, and attitudes required to do rigorous, ethical and impactful scientific work. The OECD [5] defines scientific competency based on the PISA framework as students' capacity to understand scientific phenomena, assess scientific knowledge and interpret data scientifically. PISA (2025) [6] expands on this definition emphasizing that scientific competence includes individuals engaging in reasoned discussions about science and sustainability which leads to informed action. It is the ability to apply scientific knowledge to identify questions and generate conclusions from evidence to understand and aid in decision-making regarding the nature of the world and changes in the world caused by human action. Based on PISA's [7] framework, there are 3 aspects in the scientific framework: Explain phenomena scientifically, evaluate and design scientific enquiry and interpret evidence and data scientifically. Explain phenomena scientifically means acknowledging providing and assessing explanations for various natural and technological phenomena showcasing proficiency in the following abilities: 1) Remember and apply relevant scientific knowledge. 2) Recognize, utilize, and create explanatory models and representations. 3) Formulate and substantiate appropriate predictions. 4) Propose explanatory hypotheses and 5) elaborate on the potential societal implications of scientific knowledge. Evaluate and design scientific enquiry refers to explain and assess scientific inquiries and suggest methods for addressing questions through scientific means showcasing proficiency in the following skills: 1) Recognize the question examined in a specific scientific study. 2) Differentiate questions amenable to scientific investigation. 3) Propose a method for scientifically exploring a given question. 4) Assess methods for scientifically investigating a particular question and 5) describe and evaluate the measures employed by scientists to ensure data reliability as well as the objectivity and generalizability of explanations. The last one is to interpret data and evidence scientifically. It includes the ability to examine and assess scientific data, assertions and reasoning presented in various formats and formulate valid conclusions showcasing proficiency in the following skills: 1) Convert information from one format to another. 2) Scrutinize and explain data arriving at suitable conclusions. 3) Recognize the underlying assumptions, evidence and logic in texts related to science. 4) Differentiate between arguments grounded in scientific evidence and theory versus those rooted in alternative considerations. 5) Appraise scientific arguments and evidence from diverse sources such as newspapers, the Internet, and journals. Individual characteristics, educational experiences, institutional support, and cultural context all have an impact on scientific competency. Motivation, prior knowledge, and self-efficacy are all important aspects that influence students' engagement and achievement in science [1, 8 and 9]. These competencies involve the following three interconnected dimensions: context, understanding, and attitudes. Promoting scientific competency requires a holistic approach to science education that integrates content knowledge with inquiry-based learning, problem-solving and critical thinking skills. Scientific competency is a cornerstone of scientific research and innovation, covering a range of skills, knowledge, and attitudes required for success in the scientific field. This literature review helps to improve scientific literacy, equity and excellence in STEM domains by explaining its conceptualization, evaluation, influencing variables and consequences for education and practice. Joint efforts across disciplines and sectors are needed to ensure that all individuals have the opportunity to develop and apply their scientific competencies for the benefit of society.

2.2. Technological Pedagogical Content Knowledge (TPACK)

According to Mishra and Koehler [2] technological Pedagogical Content Knowledge (TPACK) is an extension of Shulman's Pedagogical Content Knowledge (PCK) incorporating the element of technology [10]. TPACK incorporates technology into teaching practices emphasizing the need to coordinate instructional practices, content knowledge, and technological tools. It focuses on understanding learners' viewpoints, curricular objectives, teaching methods, and assessment techniques. The concept presents a progressive strategy for teachers from basic knowledge integration to the advanced level of TPACK demonstrating effective integration of technology, teaching methods and content knowledge. Therefore, TPACK is a framework that emphasizes the integration of technology, pedagogy, and content knowledge in educational practice. TPACK provides a theoretical perspective on how teachers can effectively design and implement technology-enhanced learning experiences. The level of TPACK significantly influences students' higher-order thinking abilities [11]. TPACK is fundamentally the intersection of the following three key domains: technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK). TK refers to an understanding of how to use technology tools effectively while PK involves knowledge of instructional strategies and approaches. CK encompasses subject matter knowledge. TPACK highlights the dynamic interplay across these domains underlining the importance of integrating technology in ways that improve teaching and learning outcomes across varied content areas and contexts. Since its creation, the TPACK framework has been refined and expanded to accommodate evolving trends and issues in educational technology. Researchers have explored factors influencing the development of TPACK including teacher beliefs, experiences, and professional development opportunities. TPACK offers a comprehensive framework for understanding and promoting effective technology integration in education. TPACK provides valuable guidance for teachers and researchers striving to enhance teaching and learning using technology by stressing the dynamic interplay among technological, pedagogical, and content knowledge domains. Many research studies by Stinken-Rösner, et al. [12], Yohanes et al. [13], Novi et al. [14] and Winda et al. [15] have shown a link between teachers' TPACK levels and their capabilities in planning activities and implementing teaching practices successfully. These findings suggest that teachers with higher TPACK levels tend to demonstrate more proficient skills in crafting instructional activities that integrate technology appropriately aligning them with pedagogical strategies and subject matter content. Furthermore, these teachers are frequently found to use teaching practices that leverage technology effectively to enhance student engagement, understanding, and learning outcomes. This relationship underscores the relevance of TPACK in molding teachers' instructional design abilities and teaching practices ultimately influencing the quality of education given in the classroom.

3. Research Method

3.1. Study Approach and Design

The approach used in this research is quantitative research with a survey method. This design can be used to examine the scientific competence levels among secondary school students in the northeastern region of Thailand in the post-COVID-19 era. Additionally, it seeks to elucidate the intricate relationship between students' scientific competence and the Technological Pedagogical Content Knowledge (TPACK) possessed by teaching instructors.

3.2. Population and Sample

In this study, data were collected from science teachers in secondary schools in the northeastern region of Thailand, totalling 20 provinces. The sample size was determined using Yamane's. process was contingent upon the voluntary participation of teachers from each school.

3.3. Research Instrument

The research used a questionnaire comprising 28 items related to Technological Pedagogical Content Knowledge (TPACK) adapted from Schmidt et al. [17]. The appropriateness scores for the items ranged from 4.88 to 5.00 and the reliability value was determined to be 0.95. Meanwhile, the scientific competency measurement model was adapted in accordance with the conceptual framework of PISA [7]. It consisted of five scenarios that encompass all three dimensions: Explain phenomena scientifically, evaluate and design scientific enquiry, and interpret evidence and data scientifically. The item appropriateness scores were 5.00 and its discrimination ranged from 0.33 to 0.67 and the difficulty level ranged from 0.29 to 0.75. The reliability coefficient is 0.76.

3.4. Data Collection

In this research, data collection commenced following the receipt of ethical approval for human research from the Ethical Committee of Mahasarakham University. Thailand approved this study on 23 March 2023(Ref. No. 112-399/2566). Data were gathered using the TPACK questionnaire completed by 76 participating teachers. Additionally, the assessment of students' scientific competency was conducted by the participating teachers, each collecting data from one class of students for whom they were responsible in science courses.

3.5. Data Analysis

Data obtained from tests that have been given a score are then converted to value. Converting scores into value using the formula adapting from Arikunto [18].

$$Value = (Obtain\ Score / Max\ Score) * 100$$

The scientific competency values obtained were interpreted based on the criteria presented in Table 1 [7, 19].

Table 1.
Criteria for achievement of science competency.

Value range	Criteria
>66.66	High
33.33 – 66.66	Moderate
< 33.33	Low

Source: PISA [7] and Hasan et al., [19].

Meanwhile, the simple correlation coefficient was employed to assess the relationship between the scientific competence and Technological Pedagogical Content Knowledge (TPACK) of teachers. Salkind's [20] guidelines were used to interpret correlation coefficients specifically a correlation coefficient (r) (see Table 2).

Table 2.
Criteria for interpreting correlation coefficients.

Value range	Criteria
0.81 –1.00	Very strong
0.61 –0.80	Strong
0.41 –0.60	Moderate
0.21 –0.40	Weak
0.01 –0.20	Very weak

Source: Salkind's [20].

Subsequently, simple linear regression analysis was employed to examine the impact of teachers' TPACK on students' scientific competency.

4. Results

4.1. Demographics Analysis

Table 3 presents a demographic analysis of the 76 science teachers participating in the study from schools located in the Northeastern region of Thailand. The data revealed a gender distribution of 32 (42.11%) males and 44 (57.89%) females. Regarding teaching experience, 22 (28.95%) teachers passed 2 or fewer years, 16 (21.05%) had 3-5 years, 14 (18.42%) had 6-8 years, and 24(31.58%) boast over 8 years of experience. In terms of instructional level, 41 (53.95%) teachers instructed at the lower secondary level while 35 (46.05%) taught at the higher secondary level.

Table 3.
The basic data analysis of the student.

Items		Frequency	Percentage (%)
Gender	Male	32	42.11
	Female	44	57.89
Total		76	100.00
Teaching experience	≤ 2 years	22	28.95
	3-5 years	16	21.05
	6-8 years	14	18.42
	> 8 years	24	31.58
Total		76	100.00
The instructional level	Lower secondary school	41	53.95
	Higher secondary school	35	46.05
	Total	76	100.00

The scientific competency data in this study were gathered from students at the secondary education level in the northeastern region of Thailand spanning 20 provinces and comprising a total of 76 schools with an enrollment of 1,878 students. Preliminary data revealed a distribution of 1,008(53.67%) students in lower secondary education and 870(46.33%) students in higher secondary education. Further stratification by gender indicated 686 (36.53%) male students and 1,192(63.74%) female students as detailed in Table 4.

Table 4.
The basic data analysis of the student.

Items		Frequency	Percentage (%)
Grade level	Lower secondary school	1008	53.67
	Higher secondary school	870	46.33
	Total	1878	100.00
Gender	Male	686	36.53
	Female	1192	63.47
	Total	1878	100.00

4.2. The Student's Scientific Competency

In addition, the research outcomes pertaining to the competency level of students in science were delineated in Table 5. Examination of the table revealed a moderate level of scientific competence among the student cohort. Subsequent scrutiny of the constituent elements indicated that students manifest a moderate proficiency level in the domains of "explaining phenomena scientifically" and "evaluating and designing scientific inquiry". However, students exhibited a comparatively low level of competence in the facet of "interpreting evidence and data scientifically."

Table 5.
Test analysis results of scientific competency.

Aspects	Mean	Value	Criteria
Scientific competency	10.42	41.68	Moderate
Explain phenomena scientifically.	4.09	40.90	Moderate
Evaluate and design scientific enquiry.	3.61	45.12	Moderate
Interpret evidence and data scientifically.	2.22	31.71	Low

Furthermore, when considering the distribution of students categorized by proficiency levels (see Figure 1), the majority of students exhibit a moderate level of scientific competency accounting for 47.07%. The low proficiency level was reported at 46.43% while the high proficiency level was least prevalent at 6.50%. Further scrutiny of individual components revealed that in the domain of "explaining phenomena scientifically," a significant proportion of students demonstrated a moderate proficiency level (72.52%) followed by a low proficiency level (26.10%) and a high proficiency level (1.38%). Similarly, in the realm of "evaluating and designing scientific inquiry," a considerable cohort of students demonstrated a moderate proficiency level (60.59%) followed by lower (22.58%) and higher (16.83%) proficiency levels. Regarding "interpreting evidence and data scientifically", an overwhelming majority of students exhibited a lower proficiency level (82.00%), trailed by higher (13.21%) and moderate (4.79%) proficiency levels, respectively.

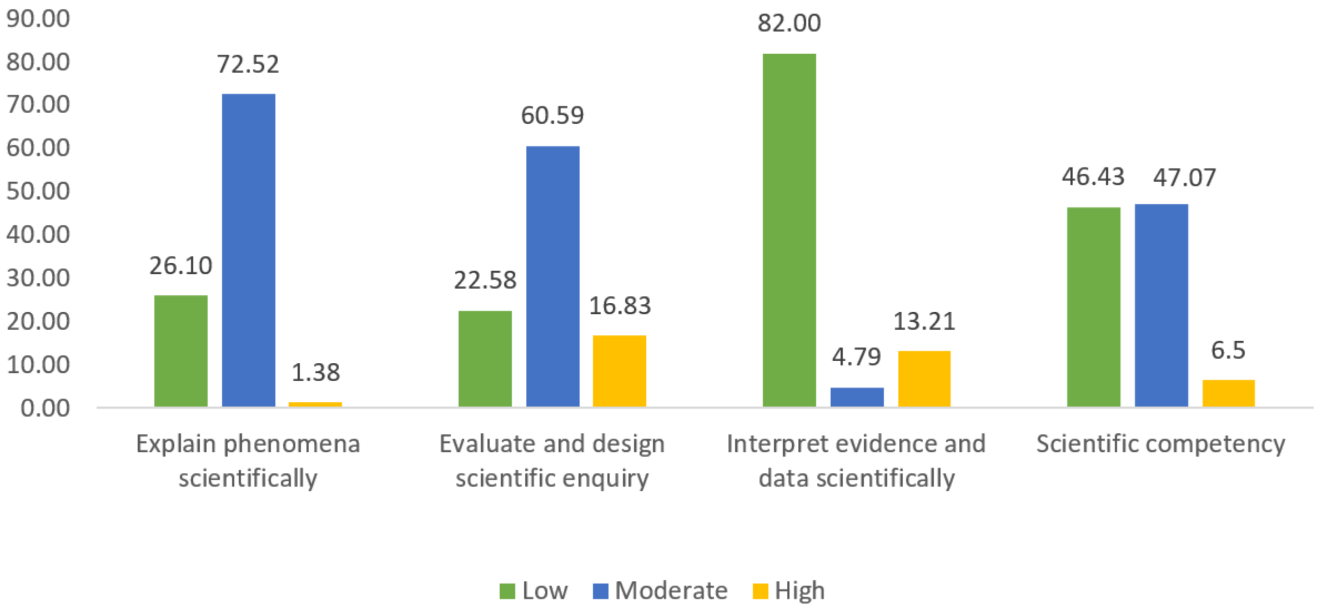

Figure 1.
The graph illustrates the percentage of students at each level of scientific competency and each component.

4.3. The Correlation Between the Scientific Competence and Technological Pedagogical Content Knowledge (TPACK) of Teachers

The study resulted in the relationship between the TPACK (Technological Pedagogical Content Knowledge) of teachers and the scientific competency of students as detailed in Table 6.

Table 6.
The correlation between the scientific competency of students and the teachers' TPACK.

ASPECTS	TPACK		
	r	P	Category
Scientific competency	0.384*	0.001	Weak
Explain phenomena scientifically.	0.301*	0.008	Weak
Evaluate and design scientific enquiry.	0.379*	0.001	Weak
Interpret evidence and data scientifically.	0.363*	0.001	Weak

Note: * $p < 0.05$.

Table 6 revealed a statistically significant correlation between the scientific competency of students and the teachers' TPACK. The computed correlation coefficient (r) of 0.384 suggested a relationship at a low level of significance. A detailed breakdown of each component of scientific competency further underscored that the observed relationships were consistently characterized by a low-level association.

Consequently, a study had been conducted to examine the impact of teachers' Technological Pedagogical Content Knowledge (TPACK) on students' scientific competency with the objective of establishing a predictive model. The findings of this study were outlined in Table 7.

Table 7.
The simple linear regression coefficient of teachers' TPACK with the scientific competency of students.

Items	B	β	SE_b	t	Sig.
Constant	5.319	0.384	0.447	3.675	0.000
Scientific competency	0.046		0.013	3.582*	0.001
R=0.384 R^2=0.148 F=12.834 P-value < 0.05					

Note: * $p < 0.05$.

From the table, it was evident that the TPACK of teachers significantly predicts the scientific competency of students at a level of .05. The variable teachers' TPACK could account for 14.80% of the variance (R2) in students' scientific competency. The predictive equation in its raw score form was represented as follows:
Y=5.319+0.046(X)

Alternatively, expressing the relationship based on the data is given in Table 7.

$$Scientific\ Competency = 5.319 + 0.046(TPACK)$$

Similarly, detailed information was provided in Tables 8, 9, and 10 upon scrutinizing individual components of scientific competency for the purpose of constructing predictive equations.

Table 8.
The simple linear regression coefficient of teachers' TPACK with the explain phenomena scientifically.

Items	B	Β	SE_b	t	Sig.
Constant	3.552	0.198	0.204	17.373	0.000
Explain phenomena scientifically.	0.005		0.002	2.719*	0.008
R=0.301 R^2=0.091 F=7.393 P-Value < 0.05					

Note: $p < 0.05$.

Table 9.
The simple linear regression coefficient of teachers' TPACK with the evaluate and design scientific enquiry.

Items	B	β	SE_b	T	Sig.
Constant	2.167	0.379	0.416	5.214	0.000
Evaluate and design scientific enquiry	0.013		0.004	3.528*	0.001
R=0.379 R^2=0.144 F=12.446 P-value < 0.05					

Note: $p < 0.05$.

Table 10.
The simple linear regression coefficient of teachers' TPACK with the interpret evidence and data scientificall.y

Items	b	β	SE_b	t	Sig.
Constant	-0.623	0.36	0.862	-0.723	0.417
Interpret evidence and data scientifically.	0.026	3	0.008	3.325*	0.001
R=0.363 R^2=0.132 F=11.238 P-value < 0.05					

Note: $p < 0.05$.

According to Table 8, the TPACK of teachers significantly predicts the explaining phenomena scientifically of students at a level of .05. The variable TPACK of teachers could account for 9.1% of the variance (R2) in students' explaining phenomena scientifically. The predictive equation in its raw score form was represented as follows:

$$Y = 3.552 + 0.005(X)$$

Alternatively, expressing the relationship based on the data is given in Table 8.

$$Explain\ phenomena\ scientifically = 3.552 + 0.005(TPACK)$$

According to Table 9, the TPACK of teachers significantly predicts students' scientific competency in "Evaluate and design scientific inquiry" at a significance level of .05. The TPACK variable could elucidate 14.4% of the variance (R2) in students' evaluation and design of scientific inquiry. The formulated predictive equation in its raw score formulation was articulated as

$$Y = 2.167 + 0.013(X)$$

Alternatively, the relational expression in accordance with the data was articulated in Table 9.

$$Evaluate\ and\ design\ scientific\ inquiry\ =\ 2.167 + 0.013(TPACK)$$

Similarly, as observed in the domain of " interpret evidence and data scientifically," data from Table 10 indicated that the TPACK of teachers significantly predicts students' scientific competency in this aspect at a significance level of .05. The TPACK variable could account for 13.2% of the variance (R2) in students' interpret evidence and data scientifically. The predictive equation in its raw score form was expressed as

$$Y = -0.623 + 0.026(X)$$

Alternatively, articulating the relationship based on the data is given in Table 10.

$$Interpret\ evidence\ and\ data\ scientifically = -0.623 + 0.026(TPACK)$$

5. Conclusion and Discussion

The assessment of science competency offers valuable insights into strengths and areas for improvement in scientific literacy. The overall scientific competency score of 9.66 reflects a moderate level of proficiency across various criteria. The lower score in data interpretation suggests a need for a targeted approach to enhance overall scientific competency while commendable strengths are observed. Regarding the specific criteria, the moderate rating for explaining phenomena scientifically indicates a reasonable level of competence in articulating scientific concepts showcasing individuals' proficiency in conveying their understanding of natural phenomena. Additionally, the moderate rating in evaluating and designing scientific enquiry demonstrates a decent level of proficiency in formulating and assessing research questions or experimental designs—a crucial competency for advancing scientific knowledge. However, there is a notable concern in the area of interpreting data and evidence scientifically as reflected in the low rating for interpreting evidence and data scientifically. This signals a specific area that requires attention and improvement. Strengthening skills in data interpretation is deemed essential for drawing accurate conclusions and making informed decisions based on scientific evidence. In a nutshell, there are commendable aspects of scientific competency addressing the identified weaknesses. Data interpretation is essential for overall improvement. Students often hold pre-existing notions about natural phenomena based on everyday experiences. These can clash with scientific concepts making them difficult to grasp. Osborne [21] highlights the following four primary obstacles that render learning science challenging: the disparity between common sense ideas and scientific principles, the requirement to comprehend abstract entities, the multifaceted nature of meaning construction using various symbols in the sciences and the lack of acknowledgment for scientific accomplishments. Therefore, this requires careful instruction that bridges the gap between common sense and scientific reasoning. Moreover, students need to understand abstract ideas.

The presented data offers a comprehensive breakdown of student performance across diverse dimensions of science competency prompting a nuanced analysis of the insights unveiled. In terms of the overall distribution, a substantial proportion of students find themselves in the "low" category for overall scientific competency signaling a pronounced necessity for significant improvement in multiple facets. Following closely, the "moderate" competency category emerges as the next most prevalent indicating a certain level of understanding but also suggesting potential for further developmental strides. Conversely, a meager 6.50% of students exhibit " high" competency underscoring the imperative to nurture exceptional skills and cultivate advanced scientific thinking. A more in-depth analysis of aspect-specific competencies reveals significant trends. In the field of explaining phenomena scientifically, a dominating 72.52% of students demonstrate "moderate" competency indicating a foundational understanding of scientific concepts and their application in clarifying phenomena. However, a significant 26.10% falls inside the "low" group indicating evident gaps in foundational knowledge or difficulty in scientific reasoning. When it comes to the evaluation and design of scientific enquiry, the majority of student exhibits a "moderate" level of competency reflecting a significant ability to design experiments and conduct data analysis. Nonetheless, a noteworthy 22.58% falls under the "low" category indicating the need for enhanced skills in generating research questions, designing investigations and evaluating evidence. The most significant problem arises in the domain of interpreting data and evidence scientifically where a large number of students fall into the "low" competency level. This highlights critical weaknesses in data analysis, interpretation and the ability to draw evidence-based conclusions. Only 4.79% and 13.21% demonstrate "moderate" and "high" competency respectively emphasizing the critical need to overcome this huge skill gap to enhance students' scientific competency. In short, a holistic strategy is required focusing not only on general competency levels but also digging into specific areas to thoroughly enhance the scientific proficiency of the student.

The alignment between students' science competency and teachers' TPACK appears as a major concern with a consistent classification of a weak relation level across various aspects of scientific competency. The identified aspects include the ability to explain phenomena scientifically, evaluate and design scientific enquiry and interpret data and evidence scientifically, collectively influencing the overall scientific competency. The low proficiency level in explaining phenomena scientifically highlights a gap between students' ability to articulate scientific concepts and the degree to which teachers can effectively integrate technological, pedagogical, and content knowledge to support this aspect of learning. Science education frequently lacks the ability to effectively bridge scientific concepts with their practical applications and relevance to students' lived experiences. This can lead to a lack of engagement and motivation as students fail to see the value and practical significance of scientific knowledge. Similarly, the weak relation level in evaluating and designing scientific enquiry indicates a challenge in aligning students' abilities in formulating and assessing research questions or experimental designs with the corresponding TPACK of teachers even though the teaching of science in Thailand may advocate for the implementation of inquiry-based learning because teachers focus on teaching subject matter or sometimes employ rote learning more than emphasizing allowing students to construct knowledge on their own through scientific methods. Teachers must shift their role from being instructors to becoming facilitators to enable students to enhance their skills and competency [22]. A critical concern is to underscore the aspect of interpreting data and evidence scientifically where the weak TPACK relation level suggests a significant disparity between students' proficiency in interpreting evidence and teachers' ability to guide and support this skill through an effective integration of technology, pedagogy, and content knowledge. Students will need higher-order thinking abilities where they must employ thinking skills such as critical thinking in problem-solving, analysis, evaluation to interpret data and present their findings in order to have competency in this area. The attainment of these higher-order thinking skills cannot be achieved through traditional teaching methods. Students need to learn through activities designed to develop advanced thinking skills or through active learning [23, 24]. However, teachers themselves may still have relatively low knowledge about higher-order thinking or may have misconceptions about it Retnawati et al. [25]. Furthermore, teachers also encounter challenges in teaching higher-order thinking in the classroom such as not knowing how to present suitable lessons, facing difficulties in designing and using higher order thinking skills-based learning materials, and learning media [26]. The overarching weak relation level in overall science competency implies a broader disconnect between what students are expected to achieve in terms of scientific proficiency and the level of TPACK possessed by their teachers. Bridging this gap is essential for creating a more cohesive and supportive learning environment where teachers can effectively leverage their TPACK to enhance students' science competency across various dimensions. Alake-Tuenter et al. [27] suggest that incorporating disciplines beyond the five sub-disciplines of science such as history and language, could enhance science instruction and deter the delivery of fragmented and isolated information. According to Yanti et al. [28] the greater the teacher's expertise in TPACK, the more involved and dynamic the students' participation in activities becomes. Hence, it can be deduced that there is a connection between teachers' TPACK proficiency and the extent of student engagement in activities. Even though the teacher may have a good TPACK, teaching science still tends to focus more on imparting content knowledge rather than fostering science competency development. This emphasis might stem from the fact that the curriculum is more subject-based rather than competency-based. As a result, teachers end up spending a significant amount of time teaching students to memorize science concepts rather than facilitating the development of scientific competency.

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