International Research Journal of Multidisciplinary Scope (IRJMS), 2026; 7(2): 1813-1830

Original Article | ISSN (O): 2582-631X DOI: 10.47857/irjms.2026.v07i02.09765

A Comparative Study of TPACK Skills of Pre-service Primary School Teachers

Fina Fakhriyah[1]*, Siti Masfuah[2], Titis Sulistyowati[3], Noor Latifah[4], Richma Hidayati[5], Sri Utaminingsih[1], Gunawan Setiadi[1]

[1]Department of Elementary Education, Universitas Muria Kudus, Central Java, Indonesia, [2]Primary Educational Teacher Department, Faculty of Teacher Training and Education, Universitas Muria Kudus, Central Java, Indonesia, [3]Department of English Education, Faculty of Teacher Training and Education, Universitas Muria Kudus, Central Java, Indonesia, [4]Departement of Information System, Faculty of Teacher Training and Education, Universitas Muria Kudus, Central Java, Indonesia, [5]Departement of Guidance and Counseling, Faculty of Teacher Training and Education, Universitas Muria Kudus, Central Java, Indonesia. *Corresponding Author's Email: fina.fakhriyah@umk.ac.id

Abstract
TPACK integrates technology, pedagogy and content in the learning context to support four teacher competencies: pedagogical, professional, social and personal. This study aimed to compare TPACK skill levels and analyze the Technological Pedagogical Content Knowledge (TPACK) of prospective elementary school teachers in Indonesia, Malaysia, the Philippines and Thailand. This comparative study applied a mixed-method approach with a sequential explanatory design. The research stages included developing and validating questionnaires and structured interviews, collecting data through questionnaires and analyzing the results to identify differences, characteristics and factors causing variations in TPACK skills across countries. SEM (Structural Equation Modelling) analysis confirmed that basic knowledge (pedagogical, content and technological knowledge) forms an essential foundation that significantly influences the development of more complex knowledge (PCK, TCK and TPK), thereby predicting core TPACK competence. The TPACK model proved to be valid and reliable (R^2 = 0.788), with significant relationships among its components, indicating that competence develops from basic knowledge (PK, CK, TK) toward integrative knowledge (PCK, TCK, TPK). Content Knowledge (CK) played a central role, with its strongest effect on TCK (β = 0.63), underscoring the importance of subject mastery as the foundation for meaningful technology integration. The findings indicated differences in TPACK mastery levels among the nations, with Malaysia achieving the highest average score. Developing TPACK competence in prospective teachers requires a holistic approach that integrates strengthened content knowledge and a synergistic pedagogical understanding.

Keywords: Comparative Study, Pre-service Teachers, SEM, TPACK.

Introduction
The transition to the Industrial Era 4.0 and Society 5.0 has spurred significant shifts in educational paradigms. The convergence of digital and physical systems has also significantly changed political, social, economic and healthcare organizations (1–3). Advances in science and technology demand adaptation across sectors to prepare teacher candidates' competencies. University students need to be proficient in 21st-century skills, such as (a) core subjects and 21st-century themes, (b) learning and innovation skills, (c) information, media and technology skills and (d) life and career skills (4). The Elementary School Teacher Education Study Program, as part of an institution that trains prospective teachers, has implemented various learning processes to improve competencies aligned with the demands of 21st-century skills. Learning in the 21st century requires integrating knowledge and skills driven by technology use, making the role of educators—particularly teacher candidates—crucial. At the very least, prospective teachers must be able to create lesson plans that incorporate effective teaching techniques for pupils with a variety of backgrounds and learning preferences (5). Furthermore, teacher competence must ensure the integration of technology in learning to optimize students' achievement of their learning needs.

TPACK skills can develop the four core competencies of teacher candidates: pedagogical, professional, social and personal (6). TPACK incorporates content, pedagogy and technology into the educational setting. It illustrates the relationship between the content, pedagogical and

(Received 19th December 2025; Accepted 17th April 2026; Published 30th April 2026)

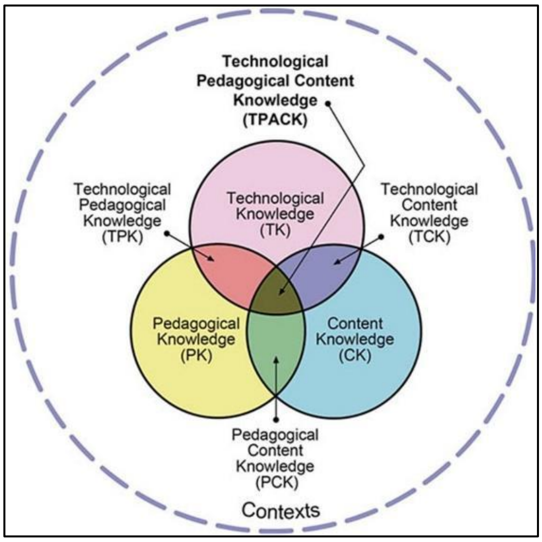

Figure 1: TPACK Concept

technological knowledge that educators need to acquire (7). The TPACK concept is shown in Figure 1.

Figure 1 illustrates that TPACK builds on content knowledge, pedagogical knowledge and technological knowledge (8–13). The combined domains within TPACK—Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK) and Pedagogical Content Knowledge (PCK)—play an important part. Other research emphasizes the value of TPACK for today's classrooms, noting that Malaysia has prioritized technology integration in school practices, particularly in teaching and learning (14). Developing learning tools with TPACK has become an essential skill that equips teacher candidates to prepare as qualified educators. This study focuses on analyzing and comparing TPACK skills across its components: CK, PCK, PK, TCK, TK, TPK and TPACK. Studies on elementary teacher candidates have found that variability in PCK strongly depends on CK and PK. Overall, TPACK skills still need improvement because the combination of technology, content and pedagogy remains suboptimal (15). A study also found that Pre-service teachers' TPACK abilities vary across components, requiring lecturers to strengthen their skills (16). Lesson planning plays a central role in ensuring successful learning. Recognizing that lesson planning plays a central role in ensuring successful learning, effective planning must guide rational decision-making to achieve specific learning objectives (17–19). Mastering TPACK is critical for elementary teacher candidates as they form the foundation of the education system. Their ability to design technology-integrated lessons will directly affect the quality of education in the future. Countries in Southeast Asia, such as Indonesia, Malaysia, Thailand and the Philippines, are highly committed to using technology to improve education. But the readiness and TPACK skills of teacher candidates varied across countries due to differences in teacher education programs, technology policies and social and cultural environments. Countries in ASEAN are dedicated to enhancing the quality of educational technologies and teacher training. Numerous member states have allocated resources towards ICT infrastructure to mitigate the digital divide and improve ICT accessibility in education (20). ASEAN nations concentrate on enhancing network capabilities for online education and enacting measures to bolster technological equity (21). There is also growing interest in establishing an international accreditation agency for teacher education institutions to improve the quality of research, teaching and learning in the field. However, there may be problems with local acceptance and global recognition (22). Consequently, a comparative analysis of TPACK competencies among elementary teacher candidates across these four nations is crucial for delineating current circumstances, identifying obstacles and highlighting exemplary implementation approaches.

An effective learning environment emphasizes pedagogy before technology. TPACK measures teachers' pedagogical, content and technical knowledge and skills in embedding technology into instruction. Researchers use the TPACK framework to explore connections between technical skills, instructional design and pedagogy. Measuring teacher candidates' TPACK skills helps assess their technological knowledge for classroom use. Each TPACK component supports others when applied in practice, making integration essential. Developing students' TPACK knowledge is crucial because combining pedagogy, content and technology creates effective learning experiences. Scholars describe TPACK as a form of multi-integration and transformation in education (23). Multi-integration reflects how pedagogy, content and technology equip teacher candidates to present material, teach effectively and provide meaningful learning (8, 24, 25). The significance of primary education is found in how well-prepared future educators are to create educational resources for young learners. For educators, mastery of the subject matter, including its frameworks, factual information, theoretical ideas and logical approaches, is a crucial prerequisite (26–28). This study responds to that urgency by comparing elementary teacher candidates' TPACK skills in Indonesia, Malaysia, the Philippines and Thailand. The analysis aims to support the development of learning tools for student exchange programs, including lesson plans, assessments, media and teaching materials.

Methodology

This study is a comparative analysis that examined differences in TPACK skills among elementary teacher candidates in Indonesia (approximate GPS coordinates 0.7893° S, 113.9213° E), Malaysia (approximate GPS coordinates 4.2105° N, 101.9758° E), Thailand (approximate GPS coordinates 15.8700° N, 100.9925° E) and Philippines (approximate GPS coordinates 12.8797° N, 121.7740° E). In addition to identifying differences and analyzing TPACK skill characteristics in each country, the study investigated the causal relationships underlying these variations. The research applied a survey-type cross-sectional design (29, 30) and used convenience sampling (31, 32) by selecting respondents from available data, students enrolled in field study courses in several education departments in Malaysia, the Philippines, Thailand and Indonesia. The research process included preparation, implementation and evaluation with reflection.

Preparation Stage

In the preparation stage, the researchers analyzed preliminary information from several universities and reviewed literature on the importance of measuring TPACK skills. After gathering initial information, they identified variables to develop measurement instruments. They then established seven indicators to measure TPACK skills of elementary teacher candidates, based on modifications and developments from previous studies (7, 11, 33). At this stage, the researchers developed a self-assessment sheet for measuring TPACK skills consisting of:

Pedagogical Knowledge (PK) is the teaching ability, a skill that must be developed by participants in school field introduction or field studies at schools as prospective teachers, so that they are able to manage and organize classes in learning activities and can achieve predetermined goals: 9 statements.

Technological Knowledge (TK) is the use of technology that must be adjusted to the times and develop continuously. Technological knowledge includes understanding how to use computer software and hardware in educational contexts. These abilities need to be possessed by prospective teachers because of the ongoing development and changes in technology: 4 statements.

Content Knowledge (CK) refers to the knowledge or specificity of a discipline or lesson. A prospective teacher is expected to master this ability. Content knowledge is also important because this ability determines the way of thinking of the discipline in each study: 4 statements.

Pedagogical Content Knowledge (PCK) is pedagogical knowledge that applies to teaching specific content. This knowledge includes knowing what approach is appropriate for the teaching process and knowing how content elements can be arranged for good learning (7) : 11 statements.

Technological Pedagogical Knowledge (TPK) is knowledge about how various technologies can be used in teaching and how their use can change the way teachers teach (34, 35). TPK arises from the reciprocal relationship between technology and pedagogy. This knowledge enables understanding of which technology is appropriate to use to achieve pedagogical goals and allows teachers to choose the right media based on feasibility and a particular pedagogical approach: 6 statements.

Technological Content Knowledge (TCK) refers to knowledge arising from the reciprocal relationship between technology and content (material). Technology will impact what is known and the introduction of new things, so that it will affect how someone can describe the content (material) in a different way than before: 5 statements.

Technological Pedagogical Content Knowledge (TPACK): TPACK is knowledge about the complex interaction of the domain of knowledge principles (content, pedagogy, technology). Learning in modern times requires teachers to understand how to collaborate with technology. So not only the pedagogical aspect but also the content and technology aspects are considered when implementing modern, innovative classroom learning. The TPACK framework also serves as a theory and framework for researchers and educators to measure the readiness of prospective and practicing teachers to teach effectively with technology. TPACK will affect teachers, given that the relationship among technology, pedagogy and content cannot be separated. So that teachers will face greater challenges in the future and these challenges are directly proportional to technological developments: 7 statements.

Implementation Stage

In the implementation stage, the researchers validated the questionnaire and interview sheet to strengthen the results of the developed questionnaire and ensure it matched the intended measurement of elementary teacher candidates' TPACK skills. They distributed the questionnaire through Google Forms, which contained seven TPACK components: TK (Technology Knowledge), PK (Pedagogical Knowledge), CK (Content Knowledge), TPK (Technological Pedagogical Knowledge), TCK (Technological Content Knowledge), PCK (Pedagogical Content Knowledge) and TPACK (Technological Pedagogical Content Knowledge). The next step involved distributing the questionnaire to respondents and collecting data.

To assess the validity of the self-assessment instrument, the researchers validated the questionnaire content with 13 experts, including physics, biology and science education experts. The validators assessed 17 items: clarity of title, diction of statements, instructions for completing the instrument, accuracy of statements, competence statements for PK, CK, TK, PCK, TCK, TPK and TPACK and sentence effectiveness and language use. Validators rated each item on a 5-point scale: 1 (strongly disagree), 2 (disagree), 3 (somewhat agree), 4 (agree) and 5 (strongly agree). The researchers analyzed content validity using CVR (Content Validity Ratio) and CVI (Content Validity Index) techniques.

a) If fewer than half of the respondents agreed or strongly agreed, CVR = -.
b) If half of the respondents agreed or strongly agreed, CVR = 0.
c) If all respondents agreed or strongly agreed, CVR = 1 (adjusted to 0.99 for the total number of respondents).
d) If more than half of the respondents agreed or strongly agreed, CVR = 0–0.99.

After obtaining the CVR index, the researchers calculated the CVI value. Table 1 shows the CVR-CVI comparison results.

Table 1: Minimum Number of Experts and Critical CVR Values for Content Validity Testing

N (Panel Size)	Proportion Agreeing Essential	$CVR_{critical}$ Exact Values	One-Sided p Value	N critical (Min. Experts Required to Agree Item Essential)—Ayre and Scally	N critical Calculated From CRITBINOM Function (36)
5	1	1.00	.031	5	4
6	1	1.00	.016	6	5
7	1	1.00	.008	7	6
8	.875	.750	.035	7	6
9	.889	.778	.020	8	7
10	.900	.800	.011	9	8
11	.818	.636	.033	9	8
12	.833	.667	.019	10	9
13	.769	.538	.046	10	9
14	.786	.571	.029	11	10

An essential step in doing a content validity analysis is calculating the Content Validity Ratio (CVR), which indicates that each item of the research instrument is deemed essential by the panel of experts. Table 1 presents the critical CVR value (CVRcritical) that is calculated using the exact binomial probability at the significance level of α=.05. According to a study, using the exact binomial distribution provides a more reliable statistical foundation than the original table by Lawshe (37), which is often considered too liberal or not suitable for small panel sizes (36). Researchers can determine the two minimal acceptance criteria needed to hold an item in an experiment by looking at the data in this table. After establishing validity threshold criteria based on the exact binomial critical value, the researchers then conducted empirical testing of each instrument item through expert panel assessments [N=13]. This evaluation included calculating the Content Validity Ratio (CVR) to assess the importance of each item and the Content Validity Index (CVI) to assess the instrument's overall relevance. A summary of the quantitative calculation results is presented in Table 2 below. The researchers compared the results in the table and presented them in Table 2.

Table 2: Expert Validation Outcomes for Research Instrument

Item Number	Ne (Frequency of 'Essential' ratings by experts)	CVR (Content Validity Ratio)	CVI (Content Validity Index)	Quantitative score means
1	10	0.538	0.769	83.077
2	11	0.692	0.846	83.077
3	11	0.692	0.846	83.077
4	9	0.385	0.692	78.462
4	10	0.538	0.769	81.538
5	12	0.846	0.923	83.077
6	13	1.000	1.000	87.692
7	13	1.000	1.000	83.077
8	13	1.000	1.000	86.154
9	11	0.692	0.846	84.615
10	11	0.692	0.846	83.077
11	11	0.692	0.846	83.077
12	11	0.692	0.846	83.077
13	11	0.692	0.846	83.077
14	11	0.692	0.846	83.077
15	11	0.692	0.846	81.538
16	8	0.231	0.615	80.000
17	10	0.538	0.769	83.077
Average	11	0.692	0.846	82.990

Evaluation Stage

In the final stage, the researchers collected data through Google Forms distributed to all respondents. They then analyzed, evaluated and interpreted the data and findings. The researchers conducted comparative tests and continued using SMART-PLS to examine the structural equation model. According to the most recent PLS-SEM guidelines, path coefficient significance and relevance are evaluated in structural model analysis using a non-parametric bootstrapping approach at predetermined significance thresholds (38). If the initial model does not fit the empirical data, researchers respecify it by modifying it and retesting it on the same dataset. The assessment of measurement models and the testing of hypotheses using SmartPLS 3.0 (39). Researchers used convergent validity and discriminant criteria to evaluate the measurement model, while they applied hypothesis testing to examine the proposed hypotheses (40).

Results and Discussion

The measurement of TPACK skills among teacher candidates aimed to determine how they implement knowledge and technology in the learning process. This comparative study described the urgency and investigated the readiness of teacher candidates in four countries. The research sought to compare TPACK skill levels and analyze Technological Pedagogical Content

Knowledge (TPACK) among elementary school teacher candidates in Indonesia, Malaysia, the Philippines and Thailand. The study used convenience sampling with 204 respondents. Data analysis began with a one-way ANOVA to identify differences in TPACK levels among countries. Table 3 presents the distribution of respondents.

Based on Table 2, respondents from the Philippines achieved the highest average TPACK score, followed by Malaysia, Thailand and Indonesia. However, the number of respondents varied greatly across countries, with relatively small samples from the Philippines and Thailand. emphasized that unbalanced sample sizes are prone to bias and low statistical power, meaning conclusions drawn from such groups cannot be applied to a broader population (41). Therefore, this dataset serves as an exploratory study that warrants follow-up research with larger sample sizes.

Table 3: Comparative Descriptive Analysis of TPACK

					95% Confidence Interval for Mean			
Country	**N**	**Mean**	**Std. Deviation**	**Std. Error**	**Lower Bound**	**Upper Bound**	**Minimum**	**Maximum**
Philippines	4	27.7500	.50000	.25000	26.9544	28.5456	27.00	28.00
Malaysia	27	24.8889	3.53372	.68006	23.4910	26.2868	18.00	28.00
Thailand	13	23.1538	4.27875	1.18671	20.5682	25.7395	14.00	28.00
Indonesia	160	22.7438	2.93803	.23227	22.2850	23.2025	13.00	28.00
Total	204	23.1520	3.22421	.22574	22.7069	23.5971	13.00	28.00

To assess whether the mean differences were statistically significant, a Welch's ANOVA was applied instead of a standard one-way ANOVA. Although the Levene Test based on the median (Table 4) indicated a non-significant result ($p = 0.104$), the extreme imbalance in sample sizes (e.g., Philippines n=4 vs. Indonesia n=160) and the substantial differences in standard deviations posed a risk to the reliability of standard F-test assumption (42). In such cases, Welch's ANOVA is a more robust alternative as it does not assume homogeneity of variance and provides a more accurate estimate of the F-statistic when group sizes are unequal (43). This approach ensures that the high mean scores in smaller groups do not disproportionately bias the overall analysis.

Table 4: Test of Homogeneity of Variances

	Data	Levene Statistic	df1	df2	Sig.
TPACK	Based on Mean	5.356	3	200	.001
	Based on Median	2.083	3	200	.104
	Based on Median and with adjusted df	2.083	3	195.599	.104
	Based on trimmed mean	5.153	3	200	.002

The homogeneity of variance assumption was evaluated using Levene's Test. Although the test yielded a significance value of 0.104 ($p > 0.05$), the extreme imbalance in sample sizes across countries (ranging from n=4 to n=160) could still compromise the power and reliability of a standard one-way ANOVA. To ensure statistical robustness and account for unequal group sizes and variances, Welch's ANOVA was performed instead of the standard F-test (43). The results of this robust equality of means test are presented in Table 5.

Table 5: Robust Test of Equality of Means (Welch's ANOVA)

Method	Statistic (F)	df1	df2
Welch	44.381	3	11.242

As shown in Table 4, the Welch's ANOVA revealed a significant difference in TPACK skills across the four countries, $F\_Welch (3, 11.24) = 44.38, p < .001$. This robust analysis confirms that the variation in TPACK scores among teachers in the Philippines, Thailand, Malaysia and Indonesia is statistically significant despite the sample size disparities. To determine specific differences between country pairs, a Games-Howell post hoc test was conducted, as it is designed for unequal variances and sample sizes. To identify specific differences between country pairs, the researchers performed the Games-Howell post hoc test. This test was selected because it is more robust and specifically designed for situations involving unequal sample sizes and variances, ensuring more reliable comparisons than the standard Least Significant Difference (LSD) or Tukey tests (44). The results of these multiple comparisons are presented in Table 6.

Table 6: International Differences in TPACK Scores: Games-Howell Results

Countries	Countries	Mean Difference	Std. Error	Significance	95% Confidence Interval
Philippines	Malaysia	2.861	1.658	.086	[-0.410, 6.132]
	Thailand	**4.596***	1.770	**.010**	[1.105, 8.087]
	Indonesia	**5.006***	1.567	**.002**	[1.915, 8.097]
Malaysia	Thailand	1.735	1.045	.099	[-0.326, 3.796]
	Indonesia	**2.145***	0.644	**.001**	[0.874, 3.415]
Thailand	Indonesia	0.410	0.893	.647	[-1.350, 2.171]

*The mean difference is significant at the 0.05 level.

The Games-Howell post hoc results indicated significant TPACK skill differences between the Philippines and Thailand ($p = 0.010$), the Philippines and Indonesia ($p = 0.002$) and Malaysia and Indonesia ($p = 0.001$). In contrast, no significant differences were found in comparisons among the Philippines, Malaysia, Thailand and Indonesia ($p > 0.05$). Based on these statistical patterns, the four countries can be categorized into two distinct clusters. The first group, comprising the Philippines and Malaysia, demonstrated higher TPACK readiness, likely due to more established and structured ICT integration policies (45, 46). The second group, comprising Thailand and Indonesia, exhibited relatively lower TPACK levels, with comparable results. This pattern suggests shared challenges in both nations, such as inconsistent policy execution and disparities in teacher professional development (47–49).

Specifically for Indonesia, these findings confirm national studies emphasizing the need to systematically enhance TPACK competence in teacher education institutioNS (48–52). Teacher candidates placed in schools with limited technological resources naturally have fewer opportunities to practice and develop TPACK skills (48–50). Consequently, despite strong national policies, uneven implementation results in a lower national average competence. Found that, although research on TPACK has expanded, building TPACK abilities among teacher candidates remains a serious concern, further highlighted by the fact that curricula in several teacher education institutions do not fully integrate the three TPACK domains meaningfully (50, 53). Technology, pedagogy and content courses are often taught separately, making it difficult for candidates to synthesize this knowledge in practical teaching.

The use of Welch's ANOVA and Games-Howell provided a robust foundation for understanding group variances, which was subsequently accounted for in the SEM analysis by applying bootstrapping techniques to mitigate the impact of unequal sample sizes. The researchers then conducted Partial Least Squares Structural Equation Modeling (PLS-SEM) to empirically examine how foundational knowledge (PK, CK, TK) influences combined knowledge (PCK, TPK, TCK) and contributes to the development of TPACK skills. This structural analysis provides quantitative evidence of significant pathways, offering deeper insight into TPACK skill formation among teacher candidates. Using PLS-SEM aligns with previous studies that employed this method to validate and analyze TPACK models among educators due to its ability to handle complex models with minimal data assumptions (41).

The researchers first evaluated the outer model to ensure that the measurement tools or constructs for each indicator were valid and reliable. Outer loading values represent the correlation or contribution of each indicator (question item in the questionnaire) to its latent construct. Table 7 presents the outer loading analysis results.

Table 7: Outer Loadings of the Measurement Model for TPACK Constructs

Indicators	PK	CK	TK	PCK	TPK	TCK	TPACK
CK1		0.777					
CK2		0.840					
CK3		0.795					
CK4		0.855					

Indicators	PK	CK	TK	PCK	TPK	TCK	TPACK
PCK1				0.768			
PCK10				0.751			
PCK2				0.776			
PCK3				0.765			
PCK4				0.822			
PCK5				0.811			
PCK6				0.796			
PCK7				0.786			
PCK8				0.776			
PCK9				0.739			
PK1	0.846						
PK2	0.858						
PK3	0.762						
PK4	0.705						
PK5	0.745						
PK6	0.711						
PK7	0.799						
PK8	0.789						
TCK1						0.779	
TCK2						0.816	
TCK3						0.826	
TCK4						0.823	
TCK5						0.848	
TK1			0.777				
TK2			0.850				
TK3			0.867				
TK4			0.874				
TPACK1							0.782
TPACK2							0.755
TPACK3							0.797
TPACK4							0.882
TPACK5							0.856
TPACK6							0.870
TPACK7							0.848
TPK1					0.654		
TPK2					0.820		
TPK3					0.866		
TPK4					0.815		
TPK5					0.835		
TPK6					0.836		

Based on the outer loading results in Table 6, only one indicator scored below 0.7, namely TPK1 [0.654]. The researchers retained this indicator because the Average Variance Extracted (AVE) test for the TPK variable met the requirement of >0.5. A past research stated that a loading value above 0.708 is considered very satisfactory, as it shows that an indicator explains more than 50% of the variance of its construct, thereby confirming that the item is valid and strongly contributes to measuring the intended concept (41).

The next step in the outer model evaluation involved testing convergent validity, which aims to confirm that indicators theoretically measuring the same latent construct actually converge into a single coherent construct. AVE values meeting this criterion provide confidence that the indicators validly cluster to represent one construct. Figure 2 presents the PLS-Path Model.

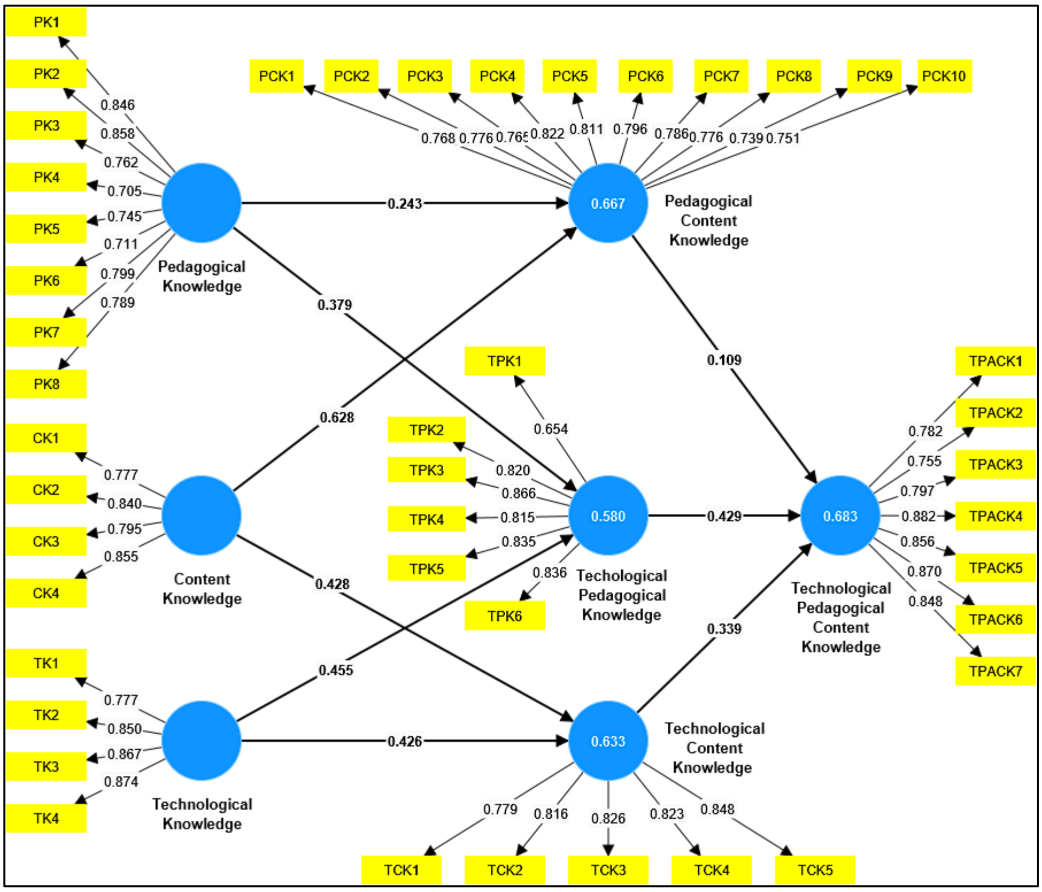

Figure 2: PLS-path Model

Table 8: Average Variance Extracted (AVE)

Construct	Average variance extracted (AVE)
Pedagogical Knowledge	0.607
Content Knowledge	0.668
Technological Knowledge	0.711
Pedagogical Content Knowledge	0.607
Technological Pedagogical Knowledge	0.652
Technological Content Knowledge	0.670
Technological Pedagogical Content Knowledge	0.687

Figure 2 illustrates the correlations between indicators and their latent constructs. To quantitatively validate the results shown in Figure 2, the researchers analyzed the Average Variance Extracted (AVE) values in Table 8. This table shows the AVE results for each construct, where values exceeding 0.50 meet the standard for satisfactory convergent validity.

The Average Variance Extracted (AVE) values for all constructs exceeded 0.50, indicating excellent convergent validity. This result shows that the indicators for each variable explained more than 50% of the variance in their construct. Thus, all constructs in the model demonstrated reliability and validity from the perspective of convergent validity, allowing the researchers to proceed confidently to the structural model (inner model) evaluation to test the hypotheses (54–56).

After confirming convergent validity and internal coherence for each construct, the next critical step in evaluating the measurement model was to establish discriminant validity. To test this, the researchers compared the classical Fornell-Larcker criterion with the Heterotrait-Monotrait (HTMT) ratio (55).

Table 9: Heterotrait-Monotrait Ratio (HTMT)

Construct	Pedagogical Knowledge	Content Knowledge	Technological Knowledge	Pedagogical Content Knowledge	Techological Pedagogical Knowledge	Technological Content Knowledge	Technological Pedagogical Content Knowledge
Pedagogical Knowledge							
Content Knowledge	0.804						
Technological Knowledge	0.738	0.858					
Pedagogical Content Knowledge	0.737	0.903	0.865				
Technological Pedagogical Knowledge	0.756	0.917	0.798	0.873			
Technological Content Knowledge	0.757	0.865	0.842	0.821	0.946		
Technological Pedagogical Content Knowledge	0.733	0.791	0.709	0.754	0.878	0.864	

The HTMT results indicated that most values remained below the critical threshold of 0.90 (Table 9). Three HTMT values exceeded 0.90: the correlation between Pedagogical Content Knowledge and Content Knowledge [0.903], Technological Pedagogical Knowledge and Content Knowledge [0.917] and Technological Content Knowledge and Technological Pedagogical Knowledge [0.946]. Thus, some constructs did not meet the criteria for discriminant validity. However, these results provided valuable empirical evidence about the developmental stage of TPACK competencies in the sample, marked by immature integration and fluid conceptual boundaries across knowledge domains. Teacher development studies confirm that differentiating and integrating these domains is a developmental process shaped by practice and reflection (12). The researchers then applied cross-validation using the Fornell-Larcker method.

Table 10: Fornell-Larcker Criterion

Konstruk	Pedagogical Knowledge	Content Knowledge	Technological Knowledge	Pedagogical Content Knowledge	Technological Pedagogical Knowledge	Technological Content Knowledge	Technological Pedagogical Content Knowledge
Pedagogical Knowledge	0.779						
Content Knowledge	0.700	0.817					
Technological Knowledge	0.665	0.736	0.843				
Pedagogical Content Knowledge	0.683	0.798	0.779	0.779			
Technological Pedagogical Knowledge	0.681	0.790	0.707	0.790	0.807		
Technological Content Knowledge	0.678	0.742	0.741	0.743	0.837	0.819	
Technological Pedagogical Content Knowledge	0.674	0.696	0.640	0.700	0.799	0.779	0.829

According to the Fornell–Larcker criterion, the square root of AVE generally exceeded the correlations among constructs in the same row or column. Nevertheless, several Fornell–Larcker values were smaller than the correlations, indicating unresolved discriminant validity issues. The Fornell–Larcker results largely supported the HTMT findings. Although many constructs met the criterion, some correlations—particularly among TPK, TCK and CK—approached or exceeded the AVE values on the diagonal (Table 10). This triangulated evidence confirmed the conceptual overlap among several knowledge domains. After completing the validity evaluation, the final step in assessing the measurement model was to ensure the internal reliability of each construct. Table 11 presents the reliability results.

Table 11: Reliability

Construct	Cronbach's alpha	Composite reliability (rho_c)
Pedagogical Knowledge	0.907	0.925
Content Knowledge	0.834	0.889
Technological Knowledge	0.864	0.907
Pedagogical Content Knowledge	0.928	0.939
Technological Pedagogical Knowledge	0.891	0.918
Technological Content Knowledge	0.877	0.910
Technological Pedagogical Content Knowledge	0.923	0.939

Table 12: R Square

Construct	R-square	R-square adjusted
Pedagogical Content Knowledge	0.667	0.664
Technological Pedagogical Knowledge	0.580	0.576
Technological Content Knowledge	0.633	0.629
Technological Pedagogical Content Knowledge	0.683	0.679

The Cronbach's Alpha values for all constructs exceeded 0.70, indicating strong internal reliability. Similarly, all Composite Reliability (CR) values exceeded 0.70, indicating high internal consistency among the indicators comprising each construct. Overall, these results confirm that all variables in the research model were reliable and suitable for further analysis.

The R^2 value for the endogenous variable Pedagogical Content Knowledge (PCK) was 0.667, meaning that 66.7% of the variance in PCK was explained by Pedagogical Knowledge (PK) and Content Knowledge (CK). This confirms that teachers' ability to transform subject matter into student-friendly forms depends heavily on the synergy between content mastery (CK) and deep pedagogical understanding (PK). The strong predictive power indicates that the tested model successfully captured the fundamental correlation validated across multiple educational research contexts (45).

The R^2 value for the endogenous variable Technological Pedagogical Knowledge (TPK) was 0.580, showing that 58% of its variance was explained by PK and Technological Knowledge (TK). Thus, preservice teachers' ability to select and use technology effectively in instruction depends not only on technical expertise (TK) but also on their pedagogical understanding (PK). This result supports arguments by (10, 11, 57), who emphasized that technology training for teachers is less effective when it focuses solely on technical skills without integrating teaching strategies.

The R^2 value for the endogenous variable Technological Content Knowledge (TCK) was 0.629, indicating that CK and TK explained 62.9% of its variance. Deep content mastery, combined with an understanding of technological tools, enables teachers to develop TCK, or knowledge of how to select the most appropriate technologies to illustrate or explain domain-specific concepts (58–60). This strong R^2 demonstrates how these two foundational knowledge domains fuse to form a new domain of expertise.

The R^2 value for the endogenous variable Technological Pedagogical Content Knowledge (TPACK) was 0.679, showing that 67.9% of its variance was explained by PCK, TPK and TCK. The model's ability to account for nearly 68% of the variance in TPACK confirms that these three integrated domains serve as relevant and significant predictors of teachers' readiness to teach effectively with technology (9, 11, 61).

Table 12 reports the f-square values, showing that the strongest effect occurred in the correlation between Content Knowledge (CK) and Pedagogical Content Knowledge (PCK) (0.604), categorised as strong. This finding confirms that content mastery (CK) serves as the most critical foundation and exerts the largest substantive impact on teachers' ability to transform subject matter into teachable and learnable forms (PCK). Strong topic knowledge among preservice teachers is a prerequisite for the success of interventions to promote PCK (11, 49, 62, 63).

Other correlations showed medium effects, such as technological knowledge on technological pedagogical knowledge [0.276] and content knowledge on technological content knowledge [0.229]. By contrast, Pedagogical Knowledge on PCK [0.091] and PCK on Technological Pedagogical Content Knowledge [0.013] were categorized as weak (Table 13). Overall, these results reinforce that CK and technological knowledge play dominant roles in shaping other constructs in the model (35, 64, 65).

Table 13: F Square

Effects	f-square
Pedagogical Knowledge -> Pedagogical Content Knowledge	0.091
Pedagogical Knowledge -> Technological Pedagogical Knowledge	0.191
Content Knowledge -> Pedagogical Content Knowledge	0.604
Content Knowledge -> Technological Content Knowledge	0.229
Technological Knowledge -> Technological Pedagogical Knowledge	0.276
Technological Knowledge -> Technological Content Knowledge	0.226
Pedagogical Content Knowledge -> Technological Pedagogical Content Knowledge	0.013
Technological Pedagogical Knowledge -> Technological Pedagogical Content Knowledge	0.137
Technological Content Knowledge -> Technological Pedagogical Content Knowledge	0.102

Table 14: Assessment of Collinearity Among Predictor Variables

Influence of Variables	VIF
Pedagogical Knowledge -> Pedagogical Content Knowledge	1.960
Pedagogical Knowledge -> Technological Pedagogical Knowledge	1.791
Content Knowledge -> Pedagogical Content Knowledge	1.960
Content Knowledge -> Technological Content Knowledge	2.183
Technological Knowledge -> Technological Pedagogical Knowledge	1.791
Technological Knowledge -> Technological Content Knowledge	2.183
Pedagogical Content Knowledge -> Technological Pedagogical Content Knowledge	2.832
Technological Pedagogical Knowledge -> Technological Pedagogical Content Knowledge	4.246
Technological Content Knowledge -> Technological Pedagogical Content Knowledge	3.558

All VIF values were below 5, indicating no multicollinearity issues in the model. Thus, all variables remained appropriate for structural model analysis. After evaluating predictive strength, the final diagnostic step before hypothesis testing was to examine multicollinearity (Table 14).

The SRMR value of 0.096 was slightly above the ideal cutoff of 0.08 but below 0.1, meaning the model was acceptable, though not a perfect fit. In general, the empirical model aligned adequately with the theoretical framework, suggesting a sufficient level of model-data fit (Table 15) (39, 54, 56, 66).

Table 15: Model fit

	Estimated model
SRMR	0.096
d_ULS	9.201
d_G	2.503
Chi-square	2362.691
NFI	0.709

Table 16: Hypothesis Test

Variable Effects	Original Sample (O)	T statistics (|O/STDEV|)	p values
Pedagogical Knowledge -> Pedagogical Content Knowledge	0.243	3.874	0.000
Content Knowledge -> Pedagogical Content Knowledge	0.628	10.312	0.000
Technological Knowledge -> Technological Content Knowledge	0.426	5.633	0.000
Content Knowledge -> Technological Content Knowledge	0.428	5.701	0.000
Technological Knowledge -> Technological Pedagogical Knowledge	0.455	7.591	0.000
Pedagogical Knowledge -> Technological Pedagogical Knowledge	0.379	6.102	0.000
Pedagogical Content Knowledge -> Technological Pedagogical Content Knowledge	0.109	1.296	0.195
Technological Content Knowledge -> Technological Pedagogical Content Knowledge	0.339	3.010	0.003
Technological Pedagogical Knowledge -> Technological Pedagogical Content Knowledge	0.429	3.114	0.002

The hypothesis tests (H1–H6) all yielded highly significant results (p = 0.000), providing strong empirical validation of the fundamental TPACK framework (Table 16). The results confirmed that combined knowledge domains (PCK, TPK, TCK) significantly emerged from the synergy of basic domains (PK, CK, TK), consistent with the core theory of TPACK. However, the most prominent finding was the consistently dominant role of Content Knowledge (CK). Specifically, the effect of CK on PCK (β = 0.628) was more than twice that of PK (β = 0.243). This dominance is logical in the context of pre-service teachers, for whom CK functions as the primary cognitive foundation. Because their pedagogical experience remains limited, CK provides a more concrete foundation than PK, which remains abstract (67).

The path coefficient of Technological Content Knowledge (TCK) on Technological Pedagogical Content Knowledge (TPACK) was 0.339, with a t-value of 3.010 > 1.96 and a p-value of 0.003 < 0.05, supporting H8. Thus, TCK significantly influenced TPACK. Previous studies have also identified TPK and TCK as significant predictors of TPACK among pre-service teachers, indicating that the practical ability to integrate technology into pedagogy and content is key (67). These findings align with structural models tested on pre-service teachers, which highlight technology-related domains as crucial antecedents. In the Indonesian context, the results support (68), who reported that TPACK components significantly influence pre-service teachers' intentions to use ICT.

The rejection of H7 carried strong theoretical significance. With a small and non-significant path coefficient (β = 0.109, p = 0.195), Pedagogical Content Knowledge (PCK) did not exert a meaningful direct effect on TPACK formation in this model. This indicates that TPACK functions as a new, transformative knowledge domain, particularly for pre-service teachers. The finding suggests that the relationship between PCK and TPACK at the start of a teaching career is not direct but develops over time with experience (67–70). Pre-service teachers' PCK often remains at an early stage of development, insufficiently internalized and too weak to serve as a foundation for integrating technological complexity. When required to teach with technology, they tend to rely more on explicit knowledge of tools and applications (TCK and TPK) gained during training. Therefore, the absence of a direct H7 path does not weaken the model; rather, it reflects the empirical reality of novice teachers' professional growth as they bridge traditional pedagogy with technology-mediated practice.

The path coefficient of Technological Pedagogical Knowledge (TPK) on TPACK was 0.429, with a t-value of 3.114 > 1.96 and a p-value of 0.002 < 0.05, supporting H9. Thus, TPK significantly influenced TPACK. TPK plays a central role in shaping TPACK, especially among pre-service teachers, because it represents knowledge of how teaching and learning practices change when specific technologies are used. TPACK emerges when teachers deliberately understand how technology can fundamentally reshape pedagogical strategies. This finding aligns with studies that stress the need for teachers to actively reflect on and redesign their pedagogical practices in light of technological possibilities (70–73). Similarly, TPK was found to be a strong predictor of TPACK among pre-service teachers, highlighting the importance of practical competence in using technology for teaching (61).

In conclusion, this study identifies significant variations in TPACK readiness among teachers across four Southeast Asian countries. The application of robust statistical analysis revealed that the Philippines and Malaysia exhibit more advanced integration of technology, pedagogy and content knowledge than Indonesia and Thailand. These differences are largely attributed to the maturity of ICT policies and the structure of teacher training programs in each nation. While the findings provide valuable insights into the regional TPACK landscape, the imbalance in sample distribution necessitates caution in generalizing the results. Nonetheless, this comparative study offers a crucial baseline for policymakers to address the specific gaps in teacher technological professional development across the region.

Conclusion

This study confirms that TPACK competence among pre-service teachers in Southeast Asia varies significantly, with Malaysia showing the highest readiness. The structural model demonstrated strong predictive power (R^2 = 0.788), validating the progression from foundational knowledge (PK, CK, TK) to integrative expertise (PCK, TCK, TPK and TPACK). he primary contribution of this research is identifying Content Knowledge (CK) as the central anchor of the TPACK framework, particularly in its strong influence on TCK ($\beta = 0.63$). This suggests a critical policy consequence: teacher preparation must shift from isolated technology training to pedagogical scaffolding, where digital tools are deeply embedded within subject-specific methodologies. Despite the robust statistical measures applied, this study has several limitations. First, the significant disparity in sample sizes across the four countries, particularly the small number of participants from the Philippines, may limit the generalizability of the findings to the broader teacher population in those regions. While Welch's ANOVA and Games-Howell tests were employed to mitigate the impact of unequal variances and group sizes, the results for groups with smaller samples should be interpreted as exploratory. Future research should aim for a more balanced and representative distribution of respondents to enhance the external validity and statistical power of the comparative analysis.

Abbreviations

None.

Acknowledgments

The authors express their sincere gratitude to Universitas Muria Kudus for providing the necessary facilities and a supportive academic environment throughout this study. We also extend our appreciation to our partner institutions for their invaluable collaboration and active participation in the data collection process. Special thanks are due to the pre-service elementary teacher respondents from Indonesia, Malaysia, the Philippines and Thailand for their time and contribution to the questionnaires and interviews. This research was made possible through the collective support and cooperation of all involved parties.

Authors Contributions

Fina Fakhriyah: supervision, conceptualization, methodology, data curation, writing – original draft, Siti Masfuah: formal analysis, resources, writing–review, editing, Titis Sulistyowati: writing – original draft, review & editing, formal analysis, Noor Latifah: data curation, supervision, methodology, Richma Hidayati : conceptualization, writing–original draft, review, editing, Sri Utaminingsih: methodology, conceptualization, investigation, project administration, Gunawan Setiadi: supervision, writing – review, editing, formal analysis, methodology.

Conflict of Interest

The author declares there is no conflict of interest.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Declaration of Generative AI And AI Assisted Technologies in the Writing Process

The authors used generative AI to assist with language editing and grammatical refinement. The authors critically reviewed and edited the output and maintain complete accountability for the originality and integrity of the published work.

Ethics Approval

This research followed the ethical guidelines for human subject research. Ethical clearance was obtained from the Research Committee of Universitas Muria Kudus. Participation was entirely voluntary and respondents were assured of their anonymity and the confidentiality of their data. No personal identifying information was collected or stored and participants retained the right to withdraw from the study at any stage without prejudice.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article

References

1. Fukuyama M. Society 5.0: Aiming for a New Human-centered Society. Japan Spotlight 2018;27(1):47–50. https://www.hitachihyoron.com/rev/archive/2017/r2017_06/pdf/p08-13_TRENDS.pdf
2. Penprase BE. The Fourth Industrial Revolution and Higher Education. In: Higher Education in the Era of the Fourth Industrial Revolution. Palgrave Macmillan; 2018. p. 207–29. doi: 10.1007/978-981-13-0194-0_9
3. Schwab K. The Fourth Industrial Revolution. NYUnited States: Crown Publishing GroupAffil. of Random House 201 East 50th Street New York,; 2017. https://law.unimelb.edu.au/__data/assets/pdf_file/0005/3385454/Schwab-The_Fourth_Industrial_Revolution_Klaus_S.pdf

4. Marzano RJ, Heflebower T. Teaching & Assessing 21st Century Skills. The Classroom Strategies Series;2012. https://api.semanticscholar.org/CorpusID:59789158
5. Smith LK, Gess-Newsome J. Elementary science methods courses and the national science education standards: Are we adequately preparing teachers? J Sci Teacher Educ. 2004;15(2):91–110. doi: 10.1023/B:JSTE.0000044867.21773.7c
6. Koehler M, Mishra P. What is technological pedagogical content knowledge (TPACK)? Contemporary issues in technology and teacher education. 2009;9(1):60–70. https://citejournal.org/volume-9/issue-1-09/general/what-is-technological-pedagogicalcontent-knowledge/
7. Mishra P, Koehler M. Technological pedagogical content knowledge: A framework for teacher knowledge. Teach Coll Rec. 2006;108(6):1017–54. doi:10.1111/j.1467-9620.2006.00684.x
8. Fabian K, Clayes E, Kelly L. Putting design into practice: an investigation of TPACK scores of lecturers in a networked institution. Research in Learning Technology. 2019;27(1063519):1–13. doi:10.25304/rlt.v27.2296
9. Chaipidech P, Kajonmanee T, Chaipah K, Panjaburee P, Srisawasdi N. Implementation of an andragogical teacher professional development training program for boosting TPACK in STEM education. Educational Technology & Society. 2021;24(4):220–39. doi:https://doi.org/48629257
10. Chaipidech P, Srisawasdi N. A Proposed Teacher Professional Development Program for Promoting Adult Teacher's TPACK in STEM Education. 2021. https://library.apsce.net/index.php/ICCE/article/view/4264/4139
11. Chai CS, Jong M, Yan Z. Surveying Chinese teachers' technological pedagogical STEM knowledge: A pilot validation of STEM-TPACK survey. International Journal of Mobile Learning and Organisation. 2020; 14(2):203–14. doi:10.1504/IJMLO.2020.106181
12. Chai CS, Koh JHL, Tsai CC. A Review of Technological Pedagogical Content Knowledge. J Educ Techno Soc. 2013 Jun 10;16(2):31–51. http://www.jstor.org/stable/jeductechsoci.16.2.31
13. Koh JHL, Chai CS, Lee MH. Technological Pedagogical Content Knowledge (TPACK) for Pedagogical Improvement: Editorial for Special Issue on TPACK. Asia-Pacific Education Researcher. Springer Singapore. 2015;459–62. doi:10.1007/s40299-015-0241-6
14. Zulkipli ZA, Mohd Yusof MM, Ibrahim N, Jamali NA. Implementation of Tpack: Preservice Teacher Motivation. International Journal of Academic Research in Progressive Education and Development. 2023;12(3):1631–9. doi:10.6007/ijarped/v12-i3/19212
15. Tanak A. Designing TPACK-based course for preparing student teachers to teach science with technological pedagogical content knowledge. Kasetsart Journal of Social Sciences. 2020;41(1):53–9. doi:10.1016/j.kjss.2018.07.012
16. Rahayu S. Do different discussion activities in developing scientific argumentation affect students' motivation in chemistry? Cakrawala Pendidikan. 2020;39(3):679–93. doi:10.21831/cp.v39i3.32228
17. Avdiu E, Bekteshi E, Gollopeni B. Learning skills for the future – implementing the 21st-century learning. Multidisciplinary Science Journal. 2025 Jan 1;7(1). doi:10.31893/multiscience.2025011
18. Wewen A, Ahmad A. The Relationship of Humanism Thinking with the Concept of Independent Learning and its Impact in the Learning Process. International Journal of Basic Educational Research. 2025 Aug 7;2(2):89–96. doi:10.14421/ijber.v2i2.10731
19. Cristóvão AM, Candeias AA, Verdasca JL. Development of Socio-Emotional and Creative Skills in Primary Education: Teachers' Perceptions About the Gulbenkian XXI School Learning Communities Project. Front Educ (Lausanne). 2020 Jan 21;4. doi:10.3389/feduc.2019.00160
20. Prajaknate P. Information Communication Technologies (ICT) for Education Projects in ASEAN: Can We Close the Digital Divide? Sustainable Development Goals in the Asian Context. Singapore: Springer Singapore. 2017:107–33. doi:10.1007/978-981-10-2815-1_6
21. Machmud MT, Widiyan AP, Ramadhani NR. The development and policies of ICT supporting educational technology in Singapore, Thailand, Indonesia and Myanmar. International Journal of Evaluation and Research in Education. 2021 Mar 1;10(1):78–85. doi:10.11591/ijere.v10i1.20786
22. Muslim AB, Hamied FA, Gaffar MF, *et al*. Benefits, mechanisms and challenges of international accreditation for teacher education: ASEAN academics' perspectives. Quality Assurance in Education. 2023 May 2;31(4): 538–55. doi:10.1108/QAE-10-2022-0183
23. Sahin I, Celik I, Oguz Akturk A, Aydin M. Analysis of Relationships between Technological Pedagogical Content Knowledge and Educational Internet Use. Journal of Digital Learning in Teacher Education. 2013 Jun 1;29(4):110–7. doi:10.1080/21532974.2013.10784714
24. Kelley TR, Knowles JG, Holland JD, Han J. Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. International Journal of STEM Education. Springer. 2020. doi:10.1186/s40594-020-00211-w
25. Glowatz M, O'Brien O. Academic Engagement and Technology: Revisiting the Technological, Pedagogical and Content Knowledge Framework (TPACK) in Higher Education (HE): The Academics' Perspectives. IAFOR Journal of Education. 2017;5 (SI):133–59. doi:10.22492/ije.5.si.06
26. Shulman LS. Knowledge and teaching: Foundations of the new reform. Harv Educ Rev. 1987;57(1):1–23. https://doi.org/10.17763/haer.57.1.j463w79r56455411
27. Ball DL, Thames MH, Phelps G. Content knowledge for teaching: What makes it special? J Teach Educ.

2008;59(5):389–407.
doi:10.1177/0022487108324554
28. Darling-Hammond L. Constructing 21st-century teacher education: Preparing teachers for what they effectively do. J Teach Educ. 2006;57(3):300–14. https://doi.org/10.1177/0022487105285962
29. Clark VLP, Creswell JW. The Mixed Methods Reader. SAGE; 2008. https://books.google.co.id/books?id=iBr6Y7cBmOQC&printsec=frontcover#v=onepage&q&f=false
30. Ivankova N V, Creswell JW, Stick SL. Using Mixed-Methods Sequential Explanatory Design: From Theory to Practice. Field methods. 2006 Feb 1;18(1): 3–20. doi:10.1177/1525822X05282260
31. Creswell JW. Research Design: Qualitative, Quantitative and Mixed Methods Approaches. SAGE Publications. 2018. https://www.ucg.ac.me/skladiste/blog_609332/objava_105202/fajlovi/Creswell.pdf
32. Creswell JW. Qualitative Inquiry and Research Design: Choosing Among Five Approaches. SAGE Publications. 2016. https://www.ceil-conicet.gov.ar/wp-content/uploads/2018/04/CRESWELLQualitative-Inquary-and-Research-Design-Creswell.pdf
33. Chai CS, Koh JHL, Teo YH. Enhancing and modeling teachers' design beliefs and efficacy of technological pedagogical content knowledge for 21st century quality learning. Journal of Educational Computing Research. 2019. doi:10.1177/0735633117752453
34. Schmidt DA, Baran E, Thompson AD, Mishra P, Koehler MJ, Shin TS. Technological pedagogical content knowledge (TPACK) the development and validation of an assessment instrument for preservice teachers. Journal of Research on Technology in Education. 2009;42(2):123–49. doi:10.1080/15391523.2009.10782544
35. Wilson FR, Pan W, Schumsky DA. Recalculation of the Critical Values for Lawshe's Content Validity Ratio. Measurement and Evaluation in Counseling and Development. 2012;45(3):197–210. doi:10.1177/0748175612440286
36. Lawshe CH. a Quantitative Approach To Content Validity. Pers Psychol. 1975;28(4):563–75. doi:10.1111/j.1744-6570.1975.tb01393.x
37. Becker JM, Cheah JH, Gholamzade R, Ringle CM, Sarstedt M. PLS-SEM's most wanted guidance. International Journal of Contemporary Hospitality Management. 2023;35(1):321–46. doi:10.1108/IJCHM-04-2022-0474
38. Hair JF, Gabriel M, Patel V. AMOS covariance-based structural equation modeling (CB-SEM): Guidelines on its application as a marketing research tool. Brazilian Journal of Marketing. 2014;13(2). doi:10.5585/remark.v13i2.2718
39. Sukarmin S, Sin I. The Influence of Principal Instructional Leadership Behaviour on The Organisational Commitment of Junior High School Teachers in Surakarta. Malaysian Journal of Learning and Instruction. 2022;19(2):69–95. doi:https://doi.org/10.32890/mjli2022.19.2.3
40. Hair JF, Black WC, Babin BJ anderson RE. Multivariate Data Analysis Eighth Edition. 2019. https://eli.johogo.com/Class/CCU/SEM/_Multivariate%20Data%20Analysis_Hair.pdf
41. Field A. Discovering statistics using IBM SPSS statistics. 4th Edition. Singapore: Sage Publications; 2013. https://sadbhavnapublications.org/research-enrichment-material/2-Statistical-Books/Discovering-Statistics-Using-IBM-SPSS-Statistics-4th-c2013-Andy-Field.pdf
42. Delacre M, Lakens D, Leys C. Why psychologists should by default use welch's t-Test instead of student's t-Test. International Review of Social Psychology. 2017;30(1):92–101. doi:10.5334/irsp.82
43. Field AP. Discovering statistics using IBM SPSS statistics : and sex and drugs and rock "n" roll . California, United States: Los Angeles : SAGE; 2013. https://searchworks.stanford.edu/view/10286094
44. Tondeur J, Scherer R, Siddiq F, Baran E. Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): A mixed-method study. Educational Technology Research and Development. 2020;68(1):319–43.
45. Phillips D, Schweisfurth M. Comparative and international education: an introduction to theory, method and practice. 2nd ed. London: Bloomsbury Academic;2014. https://www.bloomsbury.com/us/comparative-and-international-education-9781441122421/
46. Steiner-Khamsi G. Cross-national policy borrowing: Understanding reception and translation. Asia Pacific Journal of Education. 2014;34(2):153–67. doi:10.1080/02188791.2013.875649
47. Jaeni M, Ghufron MA. Developing technological pedagogical content knowledge skills during teaching practicum. International Journal of Evaluation and Research in Education (Ijere). 2024;13(3):1865. http://doi.org/10.11591/ijere.v13i3.26995
48. Humaera I, Salija K, Amin FH, Nasrullah N, Jufrianto MJM, Reskyani R. Investigating TPACK Development among Pre-service Teachers in Micro Teaching in Indonesia. The Eastasouth Journal of Learning and Educations. 2024;2(03):200–8. https://doi.org/10.58812/esle.v2i03.328
49. Dewi NR, Rusilowati A, Saptono S, *et al.* Technological, Pedagogical, Content Knowledge (TPACK) Research Trends: A Systematic Literature Review of Publications between 2010-2020. Journal of Turkish Science Education. 2021;18(4):589–604. https://doi.org/10.36681/tused.2021.92
50. Kartal T, Dilek I. Preservice science teachers' TPACK development in a technology-enhanced science teaching method course. J Educ Environ Sci Health. 2021;7(4):339–53. doi:10.21891/jeseh.994458
51. Gunanto YE, Supriyadi LA. A case study: Technological pedagogical and content knowledge (TPACK) of pre-service physics teacher to enhance the 4C's skills during online learning. Jurnal Penelitian Pendidikan IPA. 2021;7(4):660–8. doi:10.29303/jppipa.v7i4.789
52. Irwanto I. Research Trends in Technological Pedagogical Content Knowledge (TPACK): A Systematic Literature Review from 2010 to 2021. European Journal of Educational Research.

2021;10(4):2045–54. https://doi.org/10.12973/eu-jer.10.4.2045

53. Sarstedt M, Ringle CM, Hair JF. Treating unobserved heterogeneity in PLS-SEM: A multi-method approach. Partial least squares path modeling: Basic concepts, methodological issues and applications. 2017;197–217. doi:10.1007/978-3-319-64069-3_9
54. Henseler J, Ringle CM, Sarstedt M. A new criterion for assessing discriminant validity in variance-based structural equation modeling. J Acad Mark Sci. 2015;43(1):115–35. doi:10.1007/s11747-014-0403-8
55. Sarstedt M, Ringle CM, Hair JF. Partial least squares structural equation modeling. In: Handbook of market research. Springer; 2021;587–632. doi:10.1007/978-3-319-05542-8_15-2
56. Chaipidech P, Kajonmanee T, Chaipah K, Panjaburee P, Srisawasdi N. Implementation of an andragogical teacher professional development training program for boosting TPACK in STEM education. Educational Technology & Society. 2021;24(4):220–39. https://doi.org/48629257
57. Mishra P, Koehler MJ, Henriksen D. The seven trans-disciplinary habits of mind: Extending the TPACK framework towards 21st century learning. Educational Technology. 2011;22–8. https://eric.ed.gov/?id=EJ917291
58. Koehler MJ, Shin TS, Mishra P. How do we measure TPACK? Let me count the ways. Educational Technology, Teacher Knowledge and Classroom Impact: A Research Handbook on Frameworks and Approaches.2012;16–31. doi:10.4018/978-1-60960-750-0.ch002
59. Herring MC, Koehler MJ, Mishra P. Handbook of technological pedagogical content knowledge (TPACK) for educators: Second edition. Handbook of Technological Pedagogical Content Knowledge (TPACK) for Educators: Second Edition. 2nd Edition. New York: Routledge; 2016;1–338. https://doi.org/10.4324/9781315771328
60. Schmid M, Brianza E, Petko D. Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans. Comput Human Behav. 2021 Feb 1;115:106586. https://doi.org/10.1016/j.chb.2020.106586
61. Tytler R, Driel J van. Proficiencies to guide science curriculum planning. Teaching Science. 2021. doi:10.3316/informit.674960769483489
62. Chai CS, Koh JHL, Tsai CC. A review of technological pedagogical content knowledge. J Educ Techno Soc. 2013;16(2):31–51. https://www.researchgate.net/publication/290044779_A_Review_of_Technological_Pedagogical_Content_Knowledge
63. Henseler J, Ringle CM, Sarstedt M. A new criterion for assessing discriminant validity in variance-based structural equation modeling. J Acad Mark Sci. 2015; 43(1):115–35. https://doi.org/10.1007/s11747-014-0403-8
64. Tseng JJ, Chai CS, Tan L, Park M. A critical review of research on technological pedagogical and content knowledge (TPACK) in language teaching. Comput Assist Lang Learn. 2022;35(4):948–71. doi:10.1080/09588221.2020.1868531
65. Hair JF, Risher JJ, Sarstedt M, Ringle CM. When to use and how to report the results of PLS-SEM. European Business Review. 2019;31(1):2–24. doi:10.1108/EBR-11-2018-0203
66. Schmid M, Brianza E, Petko D. Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans. Comput Human Behav. 2021;115:106586. doi: 10.1016/j.chb.2020.106586
67. Habibi A, Yusop FD, Razak RA. The role of TPACK in affecting pre-service language teachers' ICT integration during teaching practices: Indonesian context. Educ Inf Technol (Dordr). 2020 May 1;25(3):1929–49. doi:10.1007/s10639-019-10040-2
68. Deng F, Chai CS, So HJ, Qian Y, Chen L. Examining the validity of the technological pedagogical content knowledge (TPACK) framework for preservice chemistry teachers. Australasian Journal of Educational Technology. 2017. doi: 10.14742/ajet.3508
69. Ye L, Ismail HH, Aziz AA. Innovative Strategies for TPACK Development in Pre-Service English Teacher Education in the 21st Century: A Systematic Review. Forum for Linguistic Studies. Bilingual Publishing Group; 2024. p. 274–94. doi:10.30564/fls.v6i6.7308
70. Papanikolaou KA, Makri K, Tzelepi MG, Zalavra E. Putting TPACK into action in learning design: The case of PeerLAND. Australasian Journal of Educational Technology. 2022. doi: 10.14742/ajet.7556
71. Kholid MN, Hendriyanto A, Sahara S, *et al.* A systematic literature review of Technological, Pedagogical and Content Knowledge (TPACK) in mathematics education: Future challenges for educational practice and research. Cogent Education. Taylor and Francis Ltd.; 2023. doi:10.1080/2331186X.2023.2269047
72. Voogt J, Fisser P, Pareja Roblin N, Tondeur J, van Braak J. Technological pedagogical content knowledge - A review of the literature. J Comput Assist Learn. 2013 Apr;29(2):109–21. doi:10.1111/j.1365-2729.2012.00487.x
73. McKenney S, Boschman F, Pieters J, Voogt J. Collaborative Design of Technology-Enhanced Learning: What can We Learn from Teacher Talk? TechTrends. 2016 Jul 1;60(4):385–91. doi:10.1007/s11528-016-0078-8

How to Cite: Fakhriyah F, Masfuah S, Sulistyowati T, Latifah N, Hidayati R, Utaminingsih S, Setiadi G. A Comparative Study of TPACK Skills of Pre-service Primary School Teachers. Int Res J Multidiscip Scope. 2026; 7(2): 1813-1830. DOI: 10.47857/irjms.2026.v07i02.09765