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TPACK AND ACADEMIC SUCCESS: A PLS-SEM STUDY IN INDONESIAN ISLAMIC UNIVERSITIES

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Abstrak

Penelitian ini bertujuan untuk menganalisis pengaruh kompetensi *Technological Pedagogical Content Knowledge* (TPACK) terhadap keberhasilan akademik mahasiswa calon guru matematika di Universitas Islam Negeri Antasari Banjarmasin. Subjek penelitian adalah 70 mahasiswa yang telah mengikuti Praktik Pengenalan Lapangan dan dipilih melalui teknik *purposive sampling*. Penelitian ini menggunakan pendekatan kuantitatif eksplanatori dengan teknik analisis *Partial Least Squares Structural Equation Modeling* (PLS-SEM). Hasil penelitian menunjukkan bahwa kompetensi TPACK berpengaruh positif dan signifikan terhadap Indeks Prestasi Kumulatif mahasiswa, meskipun ukuran efek relatif kecil sebesar 0,058. Temuan ini mengindikasikan bahwa keberhasilan akademik mahasiswa calon guru tidak hanya ditentukan oleh penguasaan teknologi dan pedagogi, tetapi juga dipengaruhi secara signifikan oleh faktor lain seperti motivasi belajar, strategi belajar mandiri, lingkungan akademik, dan dukungan sosial. Selain itu, pengaruh tidak langsung *Pedagogical Content Knowledge* (PCK) dan *Technological Pedagogical Knowledge* (TPK) terhadap GPA melalui mediasi TPACK juga terbukti signifikan. Temuan ini menunjukkan bahwa integrasi konten, pedagogi, dan teknologi mampu meningkatkan efektivitas pembelajaran serta prestasi akademik mahasiswa. Kesimpulan penelitian menekankan pentingnya pengembangan kurikulum pendidikan guru berbasis praktik yang berlandaskan refleksi integratif untuk memperkuat kompetensi TPACK.

Kata kunci: Keberhasilan Akademik; Kompetensi Guru; Pembelajaran Berbasis Teknologi; TPACK

Abstract

This study aims to analyse the influence of Technological Pedagogical Content Knowledge (TPACK) competence on the academic success of prospective mathematics teacher students at the State Islamic University of Antasari Banjarmasin. The research involved 70 students who had participated in Field Introduction Practice and were selected through purposive sampling. An explanatory quantitative approach was applied, employing Partial Least Squares Structural Equation Modelling (PLS-SEM) as the analysis technique. The findings indicate that TPACK competence has a positive and ignificant effect on student' Cumulative Grade Point Average, although the effect size is relatively small ($f^2 = 0{,}058$). This suggests that the academic success of

prospective teachers is not determined solely by technological and pedagogical competence but is also significantly influenced by other factors such as learning motivation, self-regulated learning strategies, academic environment, and social support. In addition, the indirect effects of Pedagogical Content Knowledge (PCK) and Technological Pedagogical Knowledge (TPK) on GPA, mediated by TPACK, were also significant. These results demonstrate that the integration of content, pedagogy, and technology can improve teaching effectiveness and enhance student academic achievement. The conclusion highlights the importance of developing practice-based teacher education curricula grounded in integrative reflection to strengthen TPACK competence.
Keywords: Academic Achievement; Teacher Competence; Technology-Based Learning; TPACK

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INTRODUCTION

The rapid advancement of information and communication technologies in the era of Industry 4.0 and Society 5.0 has brought substantial changes to the field of education, particularly in higher education. In Indonesia, this transformation is evident through the Merdeka Belajar–Kampus Merdeka (MBKM) policy and a growing body of empirical research demonstrating its positive impact on universities. (Susanti et al., 2023) found that MBKM implementation expands off-campus learning opportunities and enhances students' soft skills, problem-solving abilities, and workforce readiness. Similarly, (Wulandari et al., 2023) showed that digital platforms such as SPADA Indonesia support technology-based learning by providing more flexible and collaborative learning access, including for students in Islamic higher education institutions.

The utilization of national platforms such as SPADA Indonesia and the Platform Merdeka Mengajar has further accelerated the digitalization of learning and has demonstrated positive effects on student creativity and pedagogical engagement (Iswandi et al., 2025; Saputra, 2024). SPADA facilitates cross-institutional collaborative learning, whereas the Platform Merdeka Mengajar offers digital learning resources and example teaching materials that help pre-service teachers practice integrating technology into instructional design. These facilities strengthen the technological, pedagogical, and content components emphasized in the TPACK framework. However, variations in digital readiness and institutional support across universities indicate that TPACK development remains uneven, resulting in gaps in the quality of technology integration in higher education.

These developments illustrate how technology adoption directly influences curriculum design and teaching practices at Indonesian universities, including Islamic higher education institutions, where digital tools are increasingly aligned with local wisdoms and educational values. Consequently. Contemporary educators are increasingly expected not only to deliver information but also to integrate technology into their teaching methodologies, fostering innovative and pertinent learning environments (Haleem et al., 2022; Wang et al., 2023). Furthermore, the COVID-19 pandemic has emphasized the necessity of technology integration in education, compelling educators to adapt to digital platforms as essential pedagogical tools for the 21st century (Mdhlalose & Mlambo, 2023; Schleicher, 2020). Technological competence is crucial for educators to improve education quality, enhance learning outcomes, and adapt to the digital era. The Technological Pedagogical Content Knowledge framework offers a strong way to understand the knowledge teachers need to use technology effectively in their teaching (Liu et al., 2023; Su, 2023).

The TPACK framework posits that effective technology integration is not merely about using digital tools but requires a nuanced interplay between teachers' technological proficiency, pedagogical strategies, and in-depth content understanding (Bui, 2022; U.S. Department of Education, 2024). In the context of mathematics education in Indonesia, this interplay can be observed in teachers' use of digital applications such as GeoGebra to visualize algebraic and geometric concepts, interactive learning platforms to facilitate problem-based tasks, and video-based explanations to strengthen conceptual understanding. These examples illustrate how TPACK supports meaningful technology integration in mathematics classrooms and reflect emerging practices in Indonesian teacher education.

The Technological Pedagogical Content Knowledge framework, developed by Mishra and Koehler (Koehler et al., 2013; Koehler & Mishra, 2008; Mishra & Koehler, 2006; Schmidt et al., 2009), defines the competencies educators need to integrate content knowledge, pedagogy, and technology to create relevant learning experiences in today's digital environment (Isharyanti et al., 2024; Su, 2023). TPACK emphasizes that effective technology integration requires a nuanced interplay of technological proficiency, pedagogical strategies, and comprehensive content understanding (Hennessy et al., 2022; Su, 2023).

Globally, enhancing educators' digital skills is a primary educational objective; however, many countries face challenges in adequately preparing instructors to effectively use technology in the classroom (Noegroho & Zahra, 2024; UNESCO, 2023). Adopted in countries such as South Korea, Finland, and the United States to support teachers across various educational contexts, the TPACK model is essential for addressing global educational challenges by equipping teachers to integrate technology proficiently in diverse classrooms (Hennessy et al., 2022; U.S. Department of Education, 2024).

Studies indicate a positive link between TPACK proficiency and pre-service teachers' ability to create technology-enhanced lessons. Professional development effectively improves TPACK skills and teaching methods (Hennessy et al., 2022; Liu et al., 2023). TPACK experiences enhance teachers' instructional management and prepare them for the profession, with Pedagogical Content Knowledge being particularly influential. Collaborative methods like "learning by design" aid TPACK development in online settings (Hennessy et al., 2022; Isharyanti et al., 2024; Zhang & Tang, 2021).

In Indonesia, programs such as *Pendidikan Profesi Guru* and Platform *Merdeka Mengajar* have boosted TPACK skills. For instance, TPACK workshops have improved teachers' integration of technology, pedagogy, and content, aligning with the Kurikulum Merdeka (Noegroho & Zahra, 2024; Schleicher, 2023; Wang et al., 2023). A teacher's TPACK is also influenced by self-efficacy and beliefs about technology, with confidence in technological skills predicting adoption of digital innovations. Ultimately, TPACK's effectiveness depends on using technology for 21st-century learning, requiring strong educator technological proficiency (Hennessy et al., 2022; Su, 2023; Zeng et al., 2022).

Despite these initiatives, challenges remain in ensuring that teachers across Indonesia can effectively use technology. Studies indicate that providing technological resources alone is insufficient; ongoing support and targeted professional development are essential for educators to integrate technology into their teaching (Hidayat et al., 2022; Wang et al., 2023; World Bank, 2020). Furthermore, the successful integration of technology continues to face obstacles, notably infrastructure challenges, equitable access to devices, and varying levels of digital literacy across different regions (Luckyardi et al., 2024; UNESCO, 2023).

Some studies in Indonesia indicate that disparities in digital literacy skills, compounded by insufficient technical assistance and infrastructural limitations, continue to impede the seamless integration of technology within educational settings (Noegroho & Zahra, 2024; Wang et al., 2023). In response to these challenges, the *Guru Penggerak Program* has been introduced as an initiative designed to enhance teachers' reflective and collaborative skills, aligning with the principles of 21st-century learning through the contextual use of technology (Novita et al., 2022; Sari & Aslamiah, 2025; World Bank, 2020). These findings collectively highlight the multifaceted nature of TPACK implementation in Indonesia, underscoring the need for comprehensive strategies that address both technical and pedagogical dimensions to facilitate the effective integration of technology in education (UNESCO, 2023; Wang et al., 2023).

In mathematics education, TPACK mastery is highly relevant, given the abstract nature of concepts that often require visualization. Digital applications like GeoGebra and Desmos can significantly enhance student understanding through interactive explorations, helping them grasp mathematical principles more concretely (Hennessy et al., 2022; Rakes et al., 2022). Therefore, prospective mathematics teachers need well-developed TPACK competencies to optimize learning and strengthen academic achievement, effectively using technology to make abstract concepts more accessible and engaging for students (Hennessy et al., 2022; Xin et al., 2020). Furthermore, the strategic integration of technology can improve teacher performance and foster innovative pedagogical strategies that promote student engagement and better learning outcomes. Given the subject-specific nuances of technology integration, targeted professional development is essential to equip teachers with the expertise needed to effectively use digital tools in their specific subject areas (Bui, 2022; Haleem et al., 2022).

Although numerous studies have discussed the contribution of TPACK to teacher professionalism, research that directly explores the relationship between TPACK mastery and students' academic success, particularly as measured by the Cumulative Grade Point Average, remains limited (Ali & Waer, 2023; Rossi & Trevisan, 2018). TPACK mastery influences students' motivation and academic stress, which in turn affects their academic achievement. For instance, in online settings, teachers with strong TPACK skills can reduce students' stress and increase motivation, contributing to better academic results. However, more direct research is needed to fully grasp this connection across different academic fields and learning environments (Liu et al., 2023; Su, 2023). Further research should explore which specific TPACK components most significantly predict academic outcomes, providing valuable insights for curriculum development and teacher training programs, especially for 21st-century learning.

This study examines pre-service mathematics teachers at an Indonesian State Islamic University to understand the relationship between their TPACK competence and academic success. Using *Partial Least Squares Structural Equation Modeling* (PLS-SEM), the research analyzes how TPACK mastery influences Cumulative Grade Point Average (GPA). The goal is to provide empirical evidence on how integrating technology, pedagogy, and content knowledge enhances the academic performance of future mathematics teachers.

To enhance TPACK proficiency in Indonesian Islamic university teacher education, comprehensive modules are crucial, emphasizing practical digital pedagogy, micro-teaching, and reflective practice to ensure adopted tools yield efficiency, not burdens. This requires cross-curricular TPACK integration, particularly in core required courses in mathematics education, such as Calculus, Aljabar Linier, Geometry, etc. Furthermore, improving infrastructures facilities related to mathematics technologies such as interactive whiteboards, specialized graphing software, and mathematical modeling applications. Additionally, providing targeted professional development trainings and workshops such as "AI in Education" and "Digital Pedagogy for Mathematics" can further equip educators with the necessary skills to integrate technology effectively.

METHOD

This research uses an explanatory quantitative design with Partial Least Square Structural Equatioan Modeling. This design was selected because the research aims to explain the causal relationships among the dimensions of TPACK and their influence on students' academic achievement. An explanatory quantitative approach is also appropriate for identifying the directional effects among latent variables and examining how the components within the model interact.

PLS-SEM was chosen because it is capable of analyzing complex models, particularly those involving multiple latent constructs, hierarchical structures, and mediating effects. In this study, the TPACK model consists of latent variables such as CK, PK, TK, PCK, TPK, and TCK, which are interrelated and collectively influence the higher-order TPACK construct that subsequently predicts GPA. Models of this kind require an analytical technique that can handle multiple relationships simultaneously, including both direct and indirect pathways.

Unlike covariance-based Structural Equation Modeling, PLS-SEM excels in analyzing complex data with many variables and detailed relationships, even when data distributions deviate considerably from normality a common occurrence in real world educational research. In this study, "complex data" refers to the use of reflective indicators for each TPACK dimension, the presence of mediating variables, and empirical evidence showing that the distribution of students' learning outcome data tends to be non-normal. These factors further reinforce the rationale for using PLS-SEM to obtain robust and reliable estimates.

In addition, the component-based approach of PLS-SEM allows complex models to be processed more efficiently, even when indicators are highly correlated and the sample size is relatively small. These strengths make PLS-SEM suitable for research that tests causal relationships and examines various pathways among TPACK components, which aligns with this study's aim of explaining how each dimension influences students' academic achievement (Hair et al., 2021, 2022; Hoyle, 2023).

The study aims to analyze how Technological Pedagogical Content Knowledge (TPACK) influences the academic achievement of prospective mathematics teachers, as measured by their Cumulative Grade Point Average (GPA). GPA was selected as the primary indicator of academic success because it represents the most comprehensive and standardized measure of students' overall academic performance across courses, is widely used in higher education research, and reflects long-term mastery of content rather than performance on a single assessment. In addition, GPA is easily comparable across cohorts and programs, making it a valid and reliable indicator for evaluating academic achievement in this study. The model examines how core knowledge areas Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK) affect the integrated knowledge domains of Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), and Technological Content Knowledge (TCK), which collectively shape the overall TPACK construct. The analysis was performed using SmartPLS version 3, beginning with an evaluation of the measurement model to assess validity and reliability, followed by an assessment of the structural model to examine the relationships among constructs.

Bootstrapping with 5,000 subsamples was employed to determine the significance of direct, indirect, and total effects (Hair et al., 2021, 2022).

The study population consisted of 243 students in the Mathematics Education Program at the State Islamic University of Antasari Banjarmasin during the 2024/2025 academic year. From this population, 70 students were selected as the sample using purposive sampling. This selection was made because only students who had completed Field Introduction Practice and the core courses related to TPACK were considered to have sufficient knowledge and experience to provide relevant data for the study. Based on these criteria, 70 students met the requirements and were included as the final sample. This sample size also meets the guidelines for SEM-PLS, which recommend a minimum of ten times the largest number of structural paths leading to an endogenous construct.

This research model is based on the TPACK framework and involves several latent variables. Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK) function as exogenous variables that serve as the foundation for the development of TPACK competencies. These fundamental knowledge domains influence the first-level mediating constructs Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), and Technological Content Knowledge (TCK) which represent the integration of two knowledge domains. Furthermore, Technological Pedagogical Content Knowledge (TPACK) is treated as a second-level mediating construct that integrates all of these knowledge dimensions.

To clarify the structure of the model, CK, PK, and TK are understood as core knowledge domains; PCK, TPK, and TCK as integrated knowledge domains; and TPACK as the highest level of integration across all knowledge components. This hierarchical structure illustrates how basic knowledge develops into integrated knowledge, which then forms TPACK as a higher-order construct. The endogenous variable in this study is academic achievement, measured through students' Grade

Point Average (GPA) as an indicator of their cognitive performance and academic development.

Data were gathered through questionnaires and evaluations of academic records. The questionnaire was structured in the form of 46 closed-ended statements using a 5-point Likert scale, covering seven main constructs: CK, PK, TK, PCK, TPK, TCK, and TPACK. The instrument was developed from adaptations of measurement tools that have been validated in previous research. GPA data was obtained through official academic documents from the study program and used as objective data of academic success.

Data analysis was performed in two stages: descriptive analysis and inferential analysis based on SEM-PLS. Descriptive analysis was used to evaluate the level of TPACK mastery among students in general, through the calculation of the Respondent Achievement Level (RAL) or in this study called *Tingkat Capaian Responden* (TCR), using the formula:

$$TCR = (\text{Actual score} \div \text{Maximum ideal score}) \times 100\%$$

TCR categories refer to Sugiyono's guidelines (Sugiyono, 2013), as presented in Table 1.

Table 1. Categories of Respondent Achievement Level (RAL) or TCR

TCR Index (%)	Category
81 – 100	Very High
61 – 80	High
41 – 60	Moderate
21 – 40	Low
0 – 20	Very Low

Inferential analysis was performed using Smart PLS 4.0. Assessment of the measurement model (outer model) includes convergent validity test (loading > 0,70; AVE > 0,50), discriminant validity (HTMT < 0,90), and construct reliability (CR dan Cronbach's Alpha > 0,70) (Hair et al., 2021, 2022). Assessment of the structural model includes the coefficient of determination (R^2), effect size (f^2), predictive relevance ($Q^2 > 0$), and path significance through bootstrapping (5.000 subsample; $p < 0,05$; $t > 1,96$). The analysis was conducted on the direct, indirect, and total effects of each latent construct in the model (Hair et al., 2021, 2022).

The conceptual model in this study is visualized in the SEM-PLS path analysis. Three exogenous constructs CK, PK, and TK contribute to three initial mediators: PCK, TCK, and TPK. Subsequently, these three first-level mediators combine to create TPACK as a second-order construct, which, in turn, affects GPA as a measure of academic achievement.

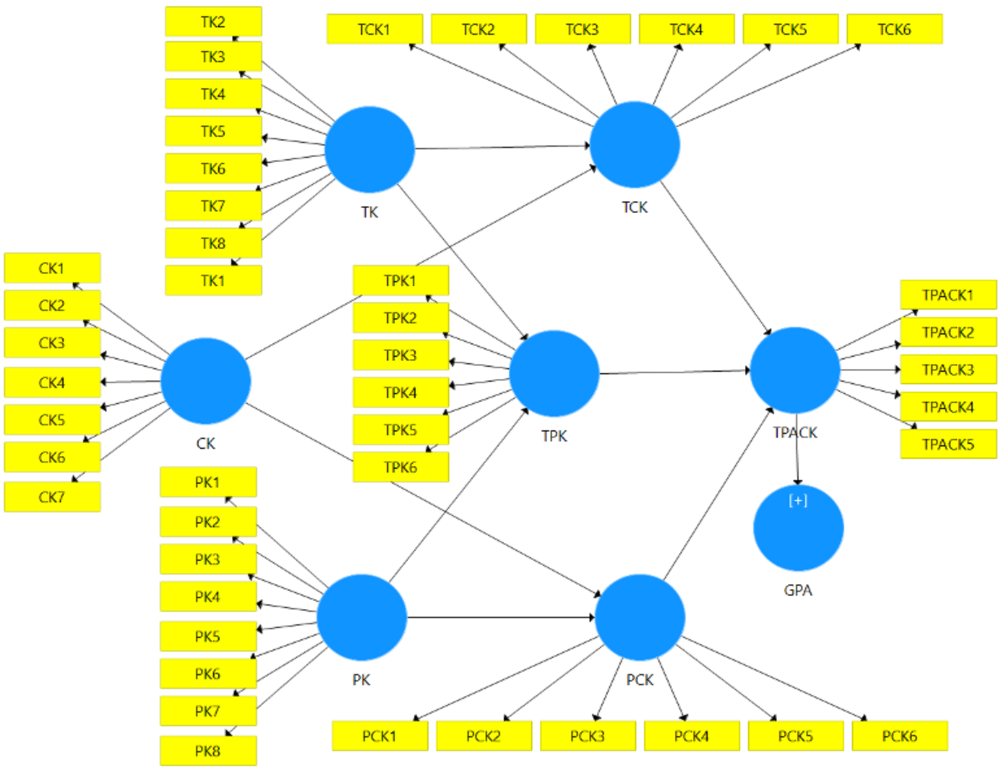

Figure 1. SEM-PLS Path Analysis Model Illustrating the Effect of TPACK on Student Academic Success

The structural model is utilized to evaluate the significance of both direct and indirect relationships between the constructs, employing bootstrapping for validation.

RESULT AND DISCUSSION

Demographic Characteristics of Respondents

Before presenting the demographic distribution, it is important to provide a brief overview of the students' background characteristics to contextualize the sample. The respondents in this study varied in gender, age, educational background, high school specialization, and prior participation in computer-related courses. These characteristics are relevant because they reflect differences in academic preparation and initial exposure to technology—factors that may influence how students engage with technology-supported learning environments and how they develop TPACK-related competencies. A detailed breakdown of these characteristics is presented in Table 1.

Table 1. Demographic Characteristics of Student Respondents

Variable	Category	Frequency	Percentage (%)
Gender	Male	14	20.00
	Female	56	80.00
Age (year)	20	12	17.14
	21	44	62.86
	22	13	18.57
	23	1	1.43
School/Educational Background	SMAN/SMA	24	34.29
	MAN/MAS	41	58.57
	SMK	5	7.14
High School Program	Natural Science (IPA)	66	94.29
	Social Science (IPS)	4	5.71
Computer Course	Yes	14	20.00
	No	56	80.00

The demographic distribution displayed in Table 1 highlights several patterns that are important for interpreting the findings of this study. The sample is predominantly female, which reflects a common trend in teacher education programs in Indonesia where women tend to enroll in higher numbers. The relatively uniform age range indicates that most students are progressing through their undergraduate studies at a typical pace, reducing potential variation due to developmental differences. The students come from diverse educational backgrounds, with many graduating from Islamic senior high schools (MAN/MAS), followed by public senior high schools (SMAN/SMA), and a smaller group from vocational schools (SMK). This diversity suggests that the sample includes students with both general academic and vocational orientations, offering broader insight into their readiness for mathematics education at the tertiary level. In terms of high school specialization, most respondents graduated from the Natural Science (IPA) track, which aligns with expectations for students pursuing mathematics education. Only a small number came from the Social Science (IPS) track. This pattern indicates that the majority likely entered the program with a stronger foundation in mathematics and related scientific subjects. Regarding technological readiness, most students had not taken computer-related courses prior to entering university, suggesting limited formal exposure to digital literacy training. This variation is meaningful when interpreting their TPACK competence and their adaptability to technology-enhanced instructional environments.

Overall, the demographic profile represents a typical cohort of pre-service mathematics teachers in Indonesian Islamic higher education, while also highlighting variations in technological experience and academic preparation that may influence the development of their TPACK competencies.

Student TPACK Competency Profile

An analysis of the seven TPACK constructs was performed using the Respondent Achievement Level method. The results are shown in Table 2.

Table 2. Average TCR Scores for Each TPACK Construct

Latent Construct	TCR Average (%)	Category
CK	69.67	High
PK	73.04	High
TK	86.32	Very High
PCK	74.57	High
TCK	73.10	High
TPK	73.86	High
TPACK	74.57	High
Overall Average	75.30	High

The TK dimension obtained the highest TCR score (86.32%), indicating that students possess exceptionally strong digital literacy. This result is reinforced by their habitual use of technology in daily life as well as by a learning environment that increasingly integrates digital tools and platforms into academic activities. As digital natives, students are already familiar with computers, smartphones, internet based platforms, and various forms of digital communication, which enables them to demonstrate a high level of confidence when operating basic technological tools. In contrast, the CK dimension recorded the lowest TCR score (69.67%), although it still falls within the high category. This relatively lower score may be attributed to the abstract and complex nature of mathematical content, which requires deep conceptual understanding and continuous practice. The relatively high proportion of neutral responses suggests that many students remain uncertain about the depth and flexibility of their mathematical conceptual mastery, particularly when compared to their technological or pedagogical competencies.

The gap between TK and CK illustrates that, despite students' strong technological proficiency, they have not yet fully leveraged these skills to enhance their understanding of mathematical content. To address this discrepancy, several strategies can be implemented, such as integrating mathematics-specific software (e.g., GeoGebra, Desmos, Maple, MATLAB) into content courses, assigning technology-assisted problem-solving tasks, providing structured TCK/TPACK workshops, and designing technology-based projects that require students to connect technological tools directly with mathematical concepts and procedures. These approaches are expected to help balance students' competencies by strengthening their content knowledge while simultaneously capitalizing on the technological strengths they already possess, ultimately supporting more meaningful and integrated mathematics learning experiences.

Measurement Model Evaluation (Outer Model)

Convergent validity is evaluated based on the outer loading value (>0.70) and AVE (>0.50). All latent constructs should meet these criteria.

Table 3. Outer Loading Values and AVE of Latent Constructs

Construct	Outer Loading (Range)	AVE
CK	0,73 – 0,91	0,72
PK	0,83 – 0,89	0,74
TK	0,70 – 0,86	0,66
PCK	0,81 – 0,87	0,69
TCK	0,79 – 0,92	0,73
TPK	0,79 – 0,91	0,73
TPACK	0,78 – 0,88	0,72

Indicator TK8 (0.70) remains within the tolerance limits and was retained based on theoretical considerations.

Construct reliability can be assessed through Cronbach's Alpha and Composite Reliability values. According to Hair et al., the ideal Cronbach's Alpha and CR values are above 0.7 (Hair et al., 2021, 2022). These values indicate the internal consistency of the indicators in measuring their constructs

Table 4. Cronbach's Alpha and Composite Reliability Values

Construct	Cronbach's Alpha	Composite Reliability
CK	0,93	0,95

Construct	Cronbach's Alpha	Composite Reliability
PK	0,95	0,96
TK	0,93	0,94
PCK	0,91	0,93
TCK	0,93	0,94
TPK	0,93	0,94
TPACK	0,90	0,93
GPA	1,00	1,00

The reliability metrics for all constructs surpassed the benchmark of 0.70, indicating robust internal consistency across the measured variables.

Discriminant validity was tested using two main approaches: the Fornell–Larcker Criterion and the Heterotrait–Monotrait Ratio (HTMT).

Table 5. Fornell–Larcker Criterion Matrix

	CK	GPA	PCK	PK	TCK	TK	TPACK	TPK
CK	**0,846**							
GPA	0,213	**1,000**						
PCK	0,772	0,250	**0,831**					
PK	0,815	0,165	0,748	**0,858**				
TCK	0,828	0,184	0,752	0,785	**0,854**			
TK	0,552	0,092	0,645	0,684	0,645	**0,811**		
TPACK	0,808	0,234	0,819	0,731	0,789	0,690	**0,846**	
TPK	0,702	0,206	0,667	0,645	0,755	0,690	0,819	**0,856**

The bold numbers on the diagonal are the square roots of the Average Variance Extracted for each construct. These values are greater than the correlations with other constructs, confirming that each construct is distinct and measurable (Hair et al., 2021, 2022).

Table 6. Heterotrait–Monotrait Ratio Matrix (HTMT)

	CK	GPA	PCK	PK	TCK	TK	TPACK	TPK
CK	–							
GPA	0,219	–						
PCK	0,831	0,257	–					
PK	0,867	0,170	0,798	–				

	CK	GPA	PCK	PK	TCK	TK	TPACK	TPK
TCK	0,884	0,188	0,810	0,833	–			
TK	0,590	0,121	0,693	0,727	0,696	–		
TPACK	0,878	0,243	0,897	0,789	0,857	0,750	–	
TPK	0,749	0,214	0,723	0,683	0,814	0,741	0,893	–

The HTMT values in Table 6 are all below 0.90, confirming good discriminant validity and indicating that each construct measures a distinct aspect. The measurement model demonstrates strong convergent validity, reliability, and discriminant validity, with Cronbach's alpha and composite reliability values confirming the consistency of the measurement scales (Hair et al., 2021, 2022; Hoyle, 2023).

Structural Model Evaluation

The coefficient of determination value indicates the ability of the independent construct to explain the variability of the dependent construct.

Table 7. R^2 and R^2 Adjusted Values of Endogenous Constructs

Construct	R^2	R^2 Adjusted	Category
GPA	0,06	0,04	Very Weak
PCK	0,64	0,63	Moderate
TCK	0,74	0,73	Strong
TPACK	0,81	0,80	Strong
TPK	0,53	0,52	Moderate

The model accounts for 81% of the variance in TPACK, indicating strong explanatory power, but only 6% for GPA, suggesting external factors significantly influence student academic performance (Hair et al., 2021; Koehler et al., 2013).

The Q^2 test, or predictive relevance value, is performed to determine the model's ability to predict observational data on endogenous indicators. According to Hair et al., a Q^2 value above 0 indicates that the model has predictive relevance to the endogenous construct (Hair et al., 2021, 2022).

Table 8. The Q² Value of Endogenous Constructs

Construct	Q²	Interpretation
TPACK	0,56	Very Strong
TCK	0,51	Strong
PCK	0,43	Strong
TPK	0,38	Moderate
GPA	0,04	Low/Weak, but Valid

The model strongly predicts mediating constructs but weakly predicts GPA. TPACK, TCK, and PCK show strong predictive relevance, whereas GPA's weak relevance suggests external factors significantly influence it.

In addition to R^2 and Q^2, the effect size (f^2) provides further insights into the contribution of predictor constructs.

Table 9. Effect Size of TPACK on GPA

Path	f²	Interpretation
TPACK → GPA	0.058	Small Effect

The analysis shows that TPACK → GPA has only a small effect size ($f^2 = 0.058$). This finding supports the earlier results, where TPACK, despite being a strong predictor of technological and pedagogical constructs, contributes only minimally to explaining student academic performance (GPA).

Direct Effect

This analysis examines the direct relationships between key concepts in the model, using path coefficients (original sample), t-statistics, and significance levels. A p-value < 0.05 indicates a statistically significant effect at a 95% confidence level. The following are the results of the path significance test:

Table 10. Direct Effect of TPACK on GPA

Path	*β*	t-value	p-Value	Explanation
TPACK → GPA	0,23	2,35	0,019	Significant

The findings reveal a significant positive relationship between TPACK and GPA, supporting previous research by Chai et al. (2013) and Yeh et al. (2021) that highlights the potential of TPACK mastery to elevate the academic achievements of future educators (Chai et al., 2013; Yeh et al., 2021).

Indirect Effect (Mediation)

Table 11. Results of mediation path analysis of TPACK dimensions on GPA

Mediation Path	*β*	t- value	p-value	Explanation
CK → PCK → TPACK → GPA	0.048	1.700	0.089	Not Significant
PCK → TPACK → GPA	0.099	2.216	0.027	Significant
PK → PCK → TPACK → GPA	0.035	1.552	0.121	Not Significant
CK → TCK → TPACK → GPA	0.024	0.989	0.323	Not Significant
TCK → TPACK → GPA	0.036	0.977	0.329	Not Significant
TK → TCK → TPACK → GPA	0.010	0.819	0.413	Not Significant
PK → TPK → TPACK → GPA	0.032	1.611	0.107	Not Significant
TPK → TPACK → GPA	0.099	2.022	0.043	Significant
TK → TPK → TPACK → GPA	0.046	1.764	0.078	Not Significant

Only two mediation paths are significant, meaning only PCK and TPK strengthen students' GPA through TPACK. Other paths, such as CK or TK → TPACK → GPA, do not show a statistically significant influence.

The findings of this study affirm that the integrated mastery of pedagogical knowledge and content knowledge exerts a far stronger influence on students' academic success than technological knowledge alone. This indicates that the most crucial factor is not merely students' ability to operate digital devices or applications, but rather their capacity to connect the use of such technologies with appropriate pedagogical reasoning and a deep conceptual understanding of mathematical content. This interpretation aligns with the core principles of the TPACK framework, which emphasizes that the integration of knowledge domains is far more meaningful than the isolated contribution of each domain.

A number of previous studies reinforce this conclusion. Hennessy et al. (2022) showed that pre-service teachers achieve greater learning gains when technology is used to support pedagogical strategies and conceptual exploration, rather than functioning merely as a technical skill. Similarly, Liu et al. (2023) found that TPK and PCK predict learning performance more strongly than TK alone, confirming that the effectiveness of technology in education depends heavily on its alignment with pedagogical objectives and the characteristics of the subject matter. Su (2023) reported comparable findings, demonstrating that students with integrated knowledge structures particularly those able to synthesize content, pedagogical, and technological knowledge exhibit more consistent academic improvement than those whose knowledge remains fragmented.

Critically, these findings suggest that technological knowledge that is not connected to content understanding or pedagogical strategy tends to remain procedural and does not directly contribute to academic outcomes such as Grade Point Average (GPA). Students may know how to use a particular technology, but without understanding why and when that technology is relevant in mathematics instruction, such knowledge becomes less meaningful for academic performance. In contrast, integrated competencies such as PCK and TPK operate at a higher cognitive level: PCK enables students to design clearer and more strategic representations of mathematical concepts, while TPK enables them to use technology to visualize ideas, enhance engagement, and facilitate mathematical reasoning more effectively.

Thus, these findings strengthen the theoretical position within TPACK scholarship that technology does not inherently improve learning outcomes unless it is integrated into sound pedagogical practices that are relevant to the content. The significant mediation effects observed in the PCK → TPACK → GPA and TPK → TPACK → GPA pathways demonstrate that the quality of knowledge integration—rather than technological skill alone plays a decisive role in determining students' academic achievement. These results also indicate that teacher education programs should place greater emphasis on developing integrated knowledge structures rather than merely increasing students' technical proficiency in using digital tools.

Overall, the findings of this study provide strong support for the argument that instructional design, curriculum development, and teacher preparation should prioritize strengthening integrated competencies across technological, pedagogical, and content domains. Such an approach is likely to yield more substantial academic benefits than initiatives that focus exclusively on improving technological skills in isolation.

Discussion

This research demonstrates that *Technological Pedagogical Content Knowledge* (TPACK) competence has a positive and significant effect on the academic success of prospective mathematics teachers, as measured by their Grade Point Average (GPA). This finding supports Mishra and Koehler's TPACK framework, highlighting that the integration of content, pedagogy, and technology knowledge is crucial for enhancing teaching effectiveness and improving learning outcomes (Harris et al., 2007; Koehler et al., 2013; Koehler & Mishra, 2008; Mishra & Koehler, 2006). The study suggests that a balanced and integrated approach to these knowledge domains contributes to a more robust understanding and application of concepts, which in turn positively influences academic performance. Furthermore, the significant effect of TPACK on academic success underscores the importance of equipping educators with the skills to effectively blend technology with their teaching practices, ensuring that they can create engaging and effective learning environments (Hennessy et al., 2022; Morales-López et al., 2021).

With respect to TPACK proficiency, the student body presents a comparatively balanced profile across all dimensions. However, the Technological Knowledge dimension appears to be the most salient, suggesting a considerable baseline familiarity with digital tools and platforms (Bui, 2022; Hennessy et al., 2022). This indicates that students possess a notable degree of confidence in their aptitude to utilize learning technologies, which is consistent with prior research indicating a predisposition towards digital modalities among prospective teacher students within the context of Education 4.0. This digital fluency offers an opportunity to leverage technology effectively in pedagogical practices, potentially enhancing engagement and learning outcomes (Haleem et al., 2022; Irwanto, 2024). Conversely, the mean Content Knowledge score is comparatively lower than other dimensions, thereby underscoring the imperative to augment the comprehension of mathematical content within the established study program. This gap highlights a critical area for enhancement, as a robust foundation in content knowledge is essential for effective teaching and the successful integration of technology and pedagogy (Hennessy et al., 2022; Su, 2023). Thus, addressing this deficiency through targeted interventions and curriculum enhancements will be vital in ensuring that prospective teachers are well-prepared to deliver high-quality mathematics instruction.

The structural model findings indicate that although TPACK directly contributes to GPA, the coefficient of determination is relatively low ($R^2 = 0.06$). This means that TPACK accounts for only 6% of the variance in GPA, which reflects **very weak explanatory power**. Furthermore, the predictive relevance test shows that GPA has a weak Q^2 value ($Q^2 = 0.04$), suggesting that the model has limited predictive ability for students' academic performance. Consistently, the effect size ($f^2 = 0.058$) for the path TPACK → GPA further confirms that the direct contribution of TPACK to GPA is only at a **small effect level**. Taken together, these three indicators (R^2, Q^2, and f^2) reinforce the conclusion that while TPACK is an important construct in shaping the integration of technological, pedagogical, and content knowledge, its direct influence on students' academic achievement is relatively minor. This implies that the academic success of prospective teacher students is not solely determined by mastery of technology and pedagogy but is also significantly influenced by other factors such as learning motivation, self-regulated learning strategies, the academic environment, and social support, as revealed in research (Bui, 2022; Su, 2023). Understanding and addressing these multifaceted influences can provide a more comprehensive approach to enhancing academic outcomes for prospective teachers. This involves a holistic strategy that not only strengthens the integration of technological, pedagogical, and content knowledge but also addresses external factors impacting academic success (Hennessy et al., 2022; Irwanto, 2024).

The mediation analysis indicates that PCK and TPK indirectly impact GPA via TPACK. This suggests that students' capacity to integrate pedagogical knowledge with content, and to incorporate technology into teaching methods, are vital for enhancing learning effectiveness (Ali & Waer, 2023; Su, 2023). These findings align with the study's broader outcomes, emphasizing the importance of combining content, pedagogy, and technology for academic success. The significant role of PCK and TPK in mediating TPACK's effect highlights that understanding how to teach specific content using technology is more impactful than mere technological proficiency (Hennessy et al., 2022; Su, 2023). This is also consistent with research showing that pedagogical reflection and technological experience positively influence pre-service teachers' academic performance (Hennessy et al., 2022; Noegroho & Zahra, 2024). The ability to critically assess and adapt teaching strategies with technological tools can improve instruction and learning outcomes, suggesting that a proactive, reflective, and technology-informed teaching approach is crucial for academic achievement. This underscores the necessity of fostering robust pedagogical content knowledge and technological pedagogical knowledge, as their interplay within the TPACK framework is pivotal for students' holistic academic development (Hidayat et al., 2022; Irwanto, 2024).

Conversely, the *Technological Content Knowledge* dimension and the *Technological Knowledge*-based mediation path did not show a significant effect on *Grade Point Average* (GPA). This suggests that merely possessing technical skills in manipulating digital content is insufficient to enhance academic success if not complemented by appropriate pedagogical strategies (Moroki & Lahamendu, 2024; Noegroho & Zahra, 2024). Effective technology integration necessitates a solid understanding of how the technology facilitates meaningful learning processes, aligning technological applications with sound instructional design principles. Without this balance, the potential of technology to improve educational outcomes remains limited, underscoring the need for educators to focus on pedagogical strategies when using technology in the classroom (Mdhlalose & Mlambo, 2023; U.S. Department of Education, 2024). This aligns with prior studies that found a discrepancy between pre-service teachers' self-reported technological proficiency and their actual classroom application, often due to practical challenges and insufficient integration of pedagogical and content knowledge (Bui, 2022; Liu et al., 2023).

In the context of Indonesian mathematics teacher education, these findings highlight the need to incorporate TPACK into university curricula. This can be done through teaching methods like lesson study, improved microteaching with technology, and using digital platforms like 'Platform *Merdeka Mengajar*' (Hennessy et al., 2022; Schleicher, 2023). These methods help teachers better understand technology's role in improving teaching, which aligns with research showing that reflecting on teaching and using technology positively affects learning outcomes. Therefore, ongoing professional development for teachers is recommended, focusing on both technical skills and thoughtful reflection on teaching methods (D'Angelo et al., 2022; Hennessy et al., 2022). This proactive approach will enable teachers to assess and adjust their strategies with technology, fostering a forward-thinking teaching style. Ultimately, the goal of integrating TPACK is to give future teachers the skills needed to create effective learning environments, improving academic achievement and preparing them for today's educational landscape (Hidayat et al., 2022; U.S. Department of Education, 2024).

Overall, this research provides empirical support for the assertion that Technological Pedagogical Content Knowledge competence is not only crucial for future teaching preparedness but also significantly contributes to academic performance during the study period (Koehler & Mishra, 2008; Liu et al., 2023; Mishra & Koehler, 2006). However, acknowledging that TPACK's influence on

Grade Point Average is only partial, it is recommended that future scholarly investigations incorporate affective variables, the learning environment, and metacognitive strategies into the predictive model of prospective teachers' academic success (Koehler et al., 2013; Rossi & Trevisan, 2018).

CONCLUSION

This study examines how Technological Pedagogical Content Knowledge affects the academic performance of future mathematics teachers at UIN Antasari Banjarmasin. Using PLS-SEM analysis, the research found the following:

1. Students have a high mastery of TPACK, with a dominance in the Technological Knowledge dimension, but mastery of Content Knowledge still needs to be improved.
2. TPACK competence has a direct, positive, and significant impact on the Grade Point Average, although its contribution to the total GPA variance is relatively low (0.06).
3. There is a significant indirect influence on GPA through the mediation path from PCK and TPK to TPACK, which confirms the importance of the integration between content, pedagogy, and technology.
4. The TCK and TK dimensions do not make a significant contribution to GPA without the involvement of pedagogical approaches, meaning technology mastery alone is insufficient for academic performance.

Overall, this research shows that Technological Pedagogical Content Knowledge, along with good teaching skills, helps mathematics education students succeed academically. It also prepares them to be good teachers in today's world.

Implications The practical implications of this research include: Higher education institutions should integrate TPACK training into teacher education curricula using methods like lesson study, technology-based microteaching, and platforms such as PMM. Policymakers should bolster digital literacy policies in PPG programs and evaluate the Merdeka Belajar curriculum's effectiveness in promoting TPACK. Lecturers and academic advisors should prioritize project-based and experiential learning focused on developing PCK and TPK, as these significantly impact student academic performance. Taken together, these actions operationalise the study's evidence into concrete steps at institutional, policy, and instructional levels, ensuring that technology integration is pedagogically meaningful and content-grounded while strengthening students' academic outcomes.

Further Research Recommendations

Further research efforts should: 1. Add other variables such as learning motivation, learning independence, or academic social support in the model to explain GPA more comprehensively. 2. Take a longitudinal approach to assess the influence of TPACK not only on GPA, but also on readiness for teaching practice in the field and performance during field experience. 3. Apply a mixed-methods model to explore the reflective dimensions and experiences of students in developing TPACK, which are not fully reflected in quantitative analysis.

Collectively, these directions extend the explanatory power of the model, capture developmental change over time, and surface rich reflective processes behind TPACK growth—thereby complementing the current quantitative findings with deeper, practice-oriented insight.

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