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# Implementation of Generative Artificial Intelligence (AI) in Learning: Analysis of Teachers' Pedagogical Readiness and Impact on Student Learning Autonomy in Indonesia

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## ABSTRACT

*This quantitative study examines the implementation of Generative Artificial Intelligence (AI) in Indonesian educational settings, focusing on teachers' pedagogical readiness and its impact on student learning autonomy. A cross-sectional survey design involving 384 teachers from various educational institutions across Indonesia was used. Data were collected using validated instruments measuring AI-TPACK (Technological Pedagogical Content Knowledge) competency and student learning autonomy. The results revealed that teachers demonstrated moderate levels of AI integration readiness (M = 3.29, SD = 0.95), with significant variations based on their teaching experience and geographic location. Multiple regression analysis indicated that AI-TPACK integration was the strongest predictor of student learning autonomy (β = 0.425, p < 0.001), explaining 61.2% of the variance. Key challenges included infrastructure limitations (75.3%), a lack of training (69.5%), and limited technical support (63.8%). The study concluded that successful AI implementation requires comprehensive teacher development programs, improved digital infrastructure, and systematic institutional support. The findings contribute to the understanding of AI integration dynamics in developing educational contexts and provide evidence for policy development in Indonesian education transformation.*

*Keywords: Artificial Intelligence, Generative AI, Teacher Readiness, Learning Autonomy, TPACK, Indonesian Education, Educational Technology*

## I. INTRODUCTION

The integration of Generative Artificial Intelligence (AI) in education represents a paradigm shift that fundamentally transforms the teaching and learning processes in the 21st century. As educational systems worldwide grapple with rapid technological advancement, the need to prepare both educators and learners for an AI-enhanced future has become increasingly critical. In Indonesia, this transformation is of particular significance as the nation implements ambitious educational reforms aimed at achieving its "Golden Generation 2045" vision, which includes mandatory AI and coding curricula for primary and secondary education starting from the 2025-2026 academic year.

The emergence of Generative AI tools such as ChatGPT, DALL-E, and other large language models has created unprecedented opportunities for educational innovation. These technologies offer capabilities that extend far beyond traditional educational software, enabling personalized learning experiences, automated content generation, intelligent tutoring systems, and sophisticated assessment mechanisms. However, the successful integration of these technologies critically depends on teachers' readiness and competency to effectively incorporate AI tools into their pedagogical practices (Bautista et al., 2024).

The Technological Pedagogical Content Knowledge (TPACK) framework, originally developed by Mishra and Koehler, provides a comprehensive theoretical foundation for understanding technology integration in education. This framework emphasizes the intersection of three primary knowledge domains: technological

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(TK), pedagogical (PK), and Content Knowledge (CK). The framework has been extensively validated across diverse educational contexts, and has proven particularly relevant for understanding teachers' competency in integrating emerging technologies.

Recent developments in AI education have necessitated the evolution of the TPACK framework to accommodate AI-specific competencies. The AI-TPACK framework extends traditional technology integration concepts to include AI literacy, ethical AI usage, and the understanding of machine learning principles. This expanded framework recognizes that AI integration requires not only technological skills but also a sophisticated understanding of how AI tools can enhance pedagogical practices while maintaining educational integrity and promoting meaningful learning outcomes (Dewi* et al., 2025).

Learning autonomy, defined as students' ability to take control of and responsibility for their own learning processes, has emerged as a critical outcome in AI-enhanced educational environments. The self-directed learning theory suggests that autonomous learners demonstrate greater engagement, motivation, and academic achievement when provided with appropriate technological support and guidance. The integration of AI tools can potentially enhance learning autonomy by providing personalized feedback, adaptive content delivery, and intelligent support systems that respond to individual learning needs.

Research indicates that AI-powered platforms can significantly enhance students' ability to personalize their learning experiences, monitor their progress, and develop metacognitive skills essential for autonomous learning. However, the relationship between AI integration and learning autonomy is complex and is mediated by various factors, including teachers' pedagogical competency, institutional support, and students' digital literacy levels (Choudhury et al., 2024).

Indonesia's educational landscape presents unique challenges and opportunities for the integration of AI. As the world's fourth most populous nation with over 270 million inhabitants, Indonesia faces significant disparities in educational access, quality, and technological infrastructure. Archipelagic geography creates substantial challenges for equitable technology distribution, with urban centers such as Jakarta and Surabaya enjoying robust digital infrastructure, while rural and remote areas often lack basic Internet connectivity (Chen & Fan, 2023).

The Indonesian Ministry of Education's decision to implement AI and coding as mandatory subjects reflects recognition of the critical importance of digital literacy for national competitiveness. This policy initiative aligns with global trends toward computational thinking and AI literacy as essential 21st-century skills. However, successful implementation requires careful consideration of existing educational infrastructure, teacher preparation programs, and regional variations in technological capacity.

Recent studies have documented significant variations in Indonesian teachers' readiness for technology integration. While urban educators often demonstrate higher levels of digital competency, rural teachers frequently lack access to opportunities for professional development and technological resources. These disparities create potential risks for widening educational inequalities if AI implementation is not carefully managed or supported (Rusmiyanto et al., 2023).

Despite growing interest in AI education, empirical research on AI integration in developing educational contexts remains limited. Most existing studies have focused on developed countries with robust technological infrastructure and well-established teacher-preparation programs. The unique challenges faced by developing nations, including Indonesia, require context-specific research to examine the intersection of technological, pedagogical, and cultural factors influencing AI adoption.

Furthermore, while numerous studies have examined technology integration using the TPACK framework, few have specifically investigated AI-TPACK competencies and their relationship to student learning outcomes. The relationship between teachers' AI integration readiness and student learning autonomy is a particularly understudied area with significant implications for educational policy and practice.

This study addresses these research gaps by examining teachers' AI TPACK readiness and its impact on student learning autonomy within the Indonesian educational context. This research contributes to the growing body of literature on AI in education while providing practical insights for policymakers, educational leaders, and teacher educators working to implement AI integration initiatives in developing educational systems.

## II. METHODS

This study employed a quantitative, cross-sectional survey design to examine the relationship between teachers' AI TPACK readiness and student learning autonomy in Indonesian educational settings. A quantitative approach was selected to enable statistical analysis of relationships between variables and to provide generalizable findings across diverse educational contexts. The cross-sectional design was appropriate,

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given the study's focus on measuring current levels of teacher readiness and student outcomes at a specific point in time during Indonesia's AI curriculum implementation phase.

The study utilized a correlational research framework to examine the strength and direction of the relationships between predictor variables (AI-TPACK components) and the criterion variable (student learning autonomy). This approach aligns with established educational research methodologies for investigating technology integration phenomena and enables rigorous statistical testing of the hypothesized relationships.

The target population comprised teachers from primary and secondary educational institutions across Indonesia, who were involved in or preparing for AI curriculum implementation. Given Indonesia's vast geographic diversity and varying levels of educational development, we employed a stratified random sampling approach to ensure representation across key demographic and geographic characteristics.

The sampling frame included teachers from public schools (63.8%), private schools (25.5%), and vocational schools (10.7%) in urban (40.6%), suburban (32.0%), rural (20.3%), and remote areas (7.0%). This distribution reflects Indonesia's educational demographic patterns, while ensuring adequate representation of diverse contexts.

Sample size determination was based on statistical power analysis using G*Power software, with parameters set for medium effect size ($f^2 = 0.15$), an alpha level of 0.05, and a power of 0.80. The analysis indicated a minimum required sample size of 346 participants. The target sample was increased to 400 participants to account for potential non-responses and incomplete, ultimately yielding 384 complete and usable responses (96.0% response rate).

The final sample comprised 384 teachers with the following demographic characteristics: 62.0% female and 38.0% male participants, reflecting the typical gender distribution in Indonesian education. The age distribution was 40.6% in the 31-40 years range, 25.5% in the 41-50 years range, 23.2% in the 25-30 years range, and 10.7% in those aged > 50 years. Teaching experience varied considerably: 34.9% had 5-10 years of experience, 29.2% had less than 5 years, 23.2% had 11-20 years, and 12.8% had more than 20 years of experience.

Educational qualifications included 51.6% with bachelor's degrees, 43.5%, master's degrees, and doctoral degrees (4.9%). The geographic distribution encompassed all major regions of Indonesia, ensuring the representation of diverse educational contexts and infrastructure levels. Participants were recruited through professional teaching associations, educational institutions, and government education offices to ensure broad representation of the target population.

The primary instrument for measuring teachers' AI integration readiness was an adapted version of the AI-TPACK scale originally developed and validated for educational technology research. The scale consists of 39 items measuring seven dimensions: Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and AI-TPACK integration.

Items were rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Sample items included: "I can effectively use AI tools to support my teaching" (AI-TPACK Integration), "I can adapt my teaching methods when using AI technology" (TPK), and "I understand how AI can enhance content delivery in my subject area" (TCK). The instrument demonstrated excellent reliability with Cronbach's alpha coefficients ranging from 0.79 to 0.91 across all subscales.

Student learning autonomy was measured using an adapted version of the Self-Directed Learning Readiness Scale (SDLRS) modified to reflect AI-enhanced learning contexts. The scale includes 30 items measuring six dimensions: self-management, learning initiatives, self-monitoring, self-evaluation, resource utilization, and goal setting. Items were rated on a 5-point Likert scale, with responses ranging from 1 (never) to 5 (always).

Representative items include: "Students effectively manage their learning time when using AI tools" (Self-Management), "Students take initiative to explore AI-based learning resources" (Learning Initiative), and "Students can evaluate the quality of AI-generated content" (Self-Evaluation). The scale demonstrated strong internal consistency with Cronbach's alpha coefficients ranging from 0.80 to 0.88 across all dimensions.

A comprehensive demographic questionnaire collected information on the participants' personal and professional characteristics, including gender, age, teaching experience, education level, school type, geographic location, and access to technological infrastructure. Additional items assessed the participants' prior experience with AI tools, participation in professional development programs, and institutional support for technology integration.

Data collection was conducted over a three-month period, from March to May 2025, utilizing both online and paper-based survey administrations to accommodate varying levels of technological access across Indonesian

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regions. Online surveys were distributed through professional networks, educational institutions, and government education offices, using secure survey platforms. Paper-based surveys were administered in regions with limited Internet connectivity, and completed forms were subsequently digitized for analysis.

Ethical approval was obtained from the institutional review board, and informed consent was obtained from all the participants. Data collection protocols ensured participant anonymity and confidentiality, while maintaining data quality through validation checks and follow-up procedures for incomplete responses. Regional coordinators assisted with data collection in remote areas to ensure geographical representation and cultural sensitivity.

Data analysis was conducted using SPSS version 29.0 and AMOS 28.0. Preliminary analyses included the examination of missing data patterns, outlier detection, and assumption testing for multivariate statistical procedures. Descriptive statistics provided a comprehensive characterization of the sample demographics and variable distributions.

Inferential statistical analyses included Pearson’s correlation analysis to examine bivariate relationships between variables, one-way ANOVA to compare group differences across demographic categories, and multiple regression analysis to identify predictors of student learning autonomy. Assumption testing confirmed the normality, linearity, and homoscedasticity requirements for the parametric statistical procedures.

Multiple regression analysis employed hierarchical entry methods, with demographic variables entered in the first step and AI-TPACK components entered in the second step. This approach enabled the assessment of the unique contribution of AI integration competency, beyond the influence of demographic factors. Effect sizes were calculated using Cohen's conventions, with eta-squared values for analysis of variance (ANOVA) and R-squared change for regression analyses.

## III. RESULTS AND DISCUSSION

### A. *Research Result*

Descriptive analysis revealed comprehensive patterns of teachers' AI integration readiness and student learning autonomy across the sample. Table 1 presents the demographic characteristics of the 384 participating teachers, showing a predominantly female sample (62.0%), with the majority being aged between 31-40 years (40.6%). The distribution of teaching experience indicated that most participants had 5-10 years of experience (34.9%), while educational qualifications were primarily at bachelor's (51.6%) and master's (43.5%) degrees.

Table 1. Demographic Characteristics of Participants (N=384)

| Characteristic | Category | Frequency | Percentage (%) |
|---|---|---|---|
| Gender | Male | 146 | 38.0 |
| | Female | 238 | 62.0 |
| Age Group | 25-30 years | 89 | 23.2 |
| | 31-40 years | 156 | 40.6 |
| | 41-50 years | 98 | 25.5 |
| | Above 50 years | 41 | 10.7 |
| Teaching Experience | Less than 5 years | 112 | 29.2 |
| | 5-10 years | 134 | 34.9 |
| | 11-20 years | 89 | 23.2 |
| | More than 20 years | 49 | 12.8 |
| Education Level | Bachelor Degree | 198 | 51.6 |
| | Master Degree | 167 | 43.5 |

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| Characteristic | Category | Frequency | Percentage (%) |
|---|---|---|---|
| | Doctoral Degree | 19 | 4.9 |
| School Type | Public School | 245 | 63.8 |
| | Private School | 98 | 25.5 |
| | Vocational School | 41 | 10.7 |
| Geographic Location | Urban | 156 | 40.6 |
| | Suburban | 123 | 32.0 |
| | Rural | 78 | 20.3 |
| | Remote Areas | 27 | 7.0 |

The geographic distribution showed strong representation from urban areas (40.6%) and suburban contexts (32.0%), with meaningful participation from rural (20.3%) and remote areas (7.0%). This distribution reflects Indonesia's demographic patterns, while ensuring adequate representation of diverse educational contexts with varying levels of technological infrastructure and support.

B. *Teacher Pedagogical Readiness Analysis*

Table 2 presents descriptive statistics for the seven components of teacher pedagogical readiness as measured by the AI-TPACK framework. The analysis revealed significant variation across different knowledge domains, with Content Knowledge demonstrating the highest mean score (M = 4.23, SD = 0.68), followed by Pedagogical Knowledge (M = 4.18, SD = 0.72), and Pedagogical Content Knowledge (M = 4.12, SD = 0.76). These findings indicate that teachers possess strong foundational knowledge in their subject areas and general pedagogical competencies.

Table 2. Descriptive Statistics for Teacher Pedagogical Readiness Components

| Component | Mean | SD | Min | Max | Cronbach's Alpha |
|---|---|---|---|---|---|
| Technological Knowledge (TK) | 3.42 | 0.89 | 1.25 | 5.00 | 0.87 |
| Pedagogical Knowledge (PK) | 4.18 | 0.72 | 2.40 | 5.00 | 0.83 |
| Content Knowledge (CK) | 4.23 | 0.68 | 2.60 | 5.00 | 0.79 |
| Technological Pedagogical Knowledge (TPK) | 3.67 | 0.84 | 1.80 | 5.00 | 0.89 |
| Technological Content Knowledge (TCK)) | 3.55 | 0.91 | 1.33 | 5.00 | 0.85 |
| Pedagogical Content Knowledge (PCK) | 4.12 | 0.76 | 2.20 | 5.00 | 0.81 |
| AI-TPACK Integration | 3.29 | 0.95 | 1.17 | 5.00 | 0.91 |

However, the technology-related competencies had considerably lower scores. Technological Knowledge received a moderate rating (M = 3.42, SD = 0.89), while AI-TPACK integration demonstrated the lowest mean score (M = 3.29, SD = 0.95), indicating significant challenges in integrating AI tools into pedagogical practices. The high standard deviation for AI-TPACK Integration (0.95) suggests substantial variation among teachers, with some demonstrating strong readiness, while others face considerable challenges.

All reliability coefficients exceeded 0.79, with the AI-TPACK integration showing excellent internal consistency ($\alpha = 0.91$), confirming the psychometric soundness of the measurement instrument. The range of

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scores across all components spanned the full scale from near-minimum to maximum values, indicating a meaningful variation in teacher competencies.

C. *Student Learning Autonomy Analysis*

Table 3 displays descriptive statistics for the six dimensions of student learning autonomy. Resource Utilization achieved the highest mean score (M = 3.83, SD = 0.73), suggesting that students effectively utilize available learning resources when supported with appropriate guidance. Self-Management also received relatively high ratings (M = 3.78, SD = 0.76), indicating students' capacity to organize and direct their learning processes.

Table 3. Descriptive Statistics for Student Learning Autonomy Dimensions

| Dimension | Mean | SD | Min | Max | Cronbach's Alpha |
|---|---|---|---|---|---|
| Self-Management | 3.78 | 0.76 | 1.67 | 5.00 | 0.84 |
| Learning Initiative | 3.65 | 0.82 | 1.33 | 5.00 | 0.86 |
| Self-Monitoring | 3.52 | 0.88 | 1.25 | 5.00 | 0.88 |
| Self-Evaluation | 3.71 | 0.79 | 1.50 | 5.00 | 0.82 |
| Resource Utilization | 3.83 | 0.73 | 1.83 | 5.00 | 0.80 |
| Goal Setting | 3.69 | 0.85 | 1.40 | 5.00 | 0.85 |

Self-monitoring demonstrated the lowest mean score (M = 3.52, SD = 0.88), suggesting challenges in students' ability to track and assess their learning progress. This finding has important implications for AI integration because the effective use of AI tools often requires sophisticated self-monitoring and metacognitive skills. The relatively high standard deviations across all dimensions indicated considerable variation in student autonomy levels, likely reflecting differences in individual characteristics, educational contexts, and institutional support. All reliability coefficients exceeded 0.80, with self-monitoring showing the highest internal consistency (α = 0.88), confirming the instrument's reliability in measuring learning autonomy in Indonesian educational contexts.

D. *Correlation Analysis*

Table 4 presents a correlation matrix that examines the relationships between the research variables. The analysis revealed significant positive correlations between all Ai and TPACK components and student learning autonomy, with correlation coefficients ranging from moderate to strong (r = 0.45 to 0.69, all $p < 0.01$). The AI-TPACK Integration demonstrated the strongest correlation with learning autonomy (r = 0.69, $p < 0.01$), followed by Technological Pedagogical Knowledge (r = 0.62, $p < 0.01$) and Pedagogical Content Knowledge (r = 0.61, $p < 0.01$).

Table 4. Correlation Matrix of Research Variables

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. Technological Knowledge (TK) | 1.00 | 0.34 | 0.29 | 0.72 | 0.68 | 0.31 | 0.78 | 0.45 |
| 2. Pedagogical Knowledge (PK) | 0.34 | 1.00 | 0.67 | 0.76 | 0.38 | 0.84 | 0.52 | 0.58 |
| 3. Content Knowledge (CK) | 0.29 | 0.67 | 1.00 | 0.41 | 0.71 | 0.89 | 0.47 | 0.53 |
| 4. Technological Pedagogical Knowledge (TPK) | 0.72 | 0.76 | 0.41 | 1.00 | 0.59 | 0.63 | 0.81 | 0.62 |
| 5. Technological Content Knowledge (TCK) | 0.68 | 0.38 | 0.71 | 0.59 | 1.00 | 0.56 | 0.74 | 0.49 |
| 6. Pedagogical Content Knowledge (PCK) | 0.31 | 0.84 | 0.89 | 0.63 | 0.56 | 1.00 | 0.58 | 0.61 |

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| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 7. AI-TPACK Integration | 0.78 | 0.52 | 0.47 | 0.81 | 0.74 | 0.58 | 1.00 | 0.69 |
| 8. Learning Autonomy | 0.45 | 0.58 | 0.53 | 0.62 | 0.49 | 0.61 | 0.69 | 1.00 |

Note: All correlations are significant at $p < 0.01$ level.

Inter-correlations among the AI-TPACK components revealed theoretically expected patterns. Strong correlations existed between related knowledge domains, such as Pedagogical Knowledge and Pedagogical Content Knowledge ($r = 0.84$, $p < 0.01$), and Content Knowledge and Pedagogical Content Knowledge ($r = 0.89$, $p < 0.01$). These findings support the theoretical coherence of the TPACK framework, while confirming the distinct contribution of AI-specific competencies.

Technological Knowledge showed strong correlations with AI-TPACK integration ($r = 0.78$, $p < 0.01$) and Technological Pedagogical Knowledge ($r = 0.72$, $p < 0.01$), indicating the foundational importance of basic technological competencies for successful AI integration. These correlation patterns provide preliminary evidence for the hypothesized relationships between teacher readiness components and student learning outcomes.

### E. *Multiple Regression Analysis*

Table 5 presents results from multiple regression analysis examining predictors of student learning autonomy. The full model explained 61.2% of the variance in learning autonomy ($R^2 = 0.612$, $F = 85.34$, $p < 0.001$), indicating a strong predictive relationship between teacher AI-TPACK competencies and student outcomes.

Table 5. Multiple Regression Analysis: Predictors of Student Learning Autonomy

| Predictor Variables | B | SE | Beta | t | p | VIF |
|---|---|---|---|---|---|---|
| Technological Knowledge (TK) | 0.185 | 0.054 | 0.192 | 3.426 | 0.001 | 2.34 |
| Pedagogical Knowledge (PK) | 0.234 | 0.067 | 0.281 | 3.493 | 0.001 | 1.89 |
| Content Knowledge (CK) | 0.158 | 0.071 | 0.164 | 2.225 | 0.027 | 2.45 |
| Tech. Pedagogical Knowledge (TPK) | 0.267 | 0.059 | 0.298 | 4.525 | 0.000 | 2.67 |
| Technological Content Knowledge (TCK) | 0.142 | 0.048 | 0.155 | 2.958 | 0.003 | 2.12 |
| Pedagogical Content Knowledge (PCK) | 0.201 | 0.063 | 0.238 | 3.190 | 0.002 | 2.78 |
| AI-TPACK Integration | 0.389 | 0.052 | 0.425 | 7.481 | 0.000 | 1.95 |

AI-TPACK Integration emerged as the strongest predictor ($\beta = 0.425$, $p < 0.001$), followed by Technological Pedagogical Knowledge ($\beta = 0.298$, $p < 0.001$) and Pedagogical Knowledge ($\beta = 0.281$, $p < 0.001$). These findings suggest that teachers' ability to effectively integrate AI tools into their pedagogical practices has the greatest impact on student learning autonomy beyond the influence of general technological or pedagogical competencies.

All predictor variables demonstrated significant contributions to the model, with variance inflation factors (VIF) ranging from 1.89 to 2.78, indicating acceptable levels of multicollinearity. The standardized beta coefficients revealed the relative importance of different competency areas, with technology integration components (AI-TPACK Integration, TPK, TK) showing stronger effects than content-focused components (CK, PCK).

### F. *Group Comparisons by Teaching Experience*

Table 6 examines the differences in AI-TPACK integration and learning autonomy across teaching experience groups. ANOVA results revealed significant group differences for both AI-TPACK integration ($F(3,380) = 12.45$, $p < 0.001$, $\eta^2 = 0.089$) and learning autonomy ($F(3,380) = 8.67$, $p < 0.001$, $\eta^2 = 0.064$).

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Table 6. AI-TPACK Integration and Learning Autonomy by Teaching Experience

| Teaching Experience | AI-TPACK Mean | AI-TPACK SD | Learning Autonomy Mean | Learning Autonomy SD |
|---|---|---|---|---|
| Less than 5 years (n=112) | 3.51 | 0.87 | 3.82 | 0.74 |
| 5-10 years (n=134) | 3.38 | 0.92 | 3.75 | 0.78 |
| 11-20 years (n=89) | 3.15 | 0.98 | 3.58 | 0.85 |
| More than 20 years (n=49) | 2.89 | 1.05 | 3.45 | 0.91 |

Teachers with less than five years of experience demonstrated the highest levels of AI-TPACK integration ($M = 3.51$, $SD = 0.87$), while those with more than 20 years of experience showed the lowest levels ($M = 2.89$, $SD = 1.05$). This pattern suggests that newer teachers may be more adaptable to emerging technologies, whereas experienced teachers may face greater challenges in adopting novel pedagogical approaches.

Post-hoc analyses using Tukey's HSD revealed significant differences between newer teachers (less than 5 years and 5-10 years) and more experienced teachers (11-20 years and more than 20 years). These findings have important implications for professional development programs, suggesting the need for differentiated approaches based on career stages and prior experience with technology integration.

G. *Geographic Location Analysis*

Table 7 presents comparisons across geographic locations, revealing substantial disparities in AI integration and supporting infrastructure. Urban teachers demonstrated significantly higher AI-TPACK Integration scores ($M = 3.67$, $SD = 0.78$) compared to rural ($M = 2.98$, $SD = 1.02$) and remote area teachers ($M = 2.45$, $SD = 1.15$). ANOVA results confirmed significant group differences ($F(3,380) = 28.73$, $p < 0.001$, $\eta^2 = 0.185$).

Table 7. AI Integration and Learning Outcomes by Geographic Location

| Geographic Location | AI-TPACK Mean | AI-TPACK SD | Learning Autonomy Mean | Learning Autonomy SD | Infrastructure Index | Training Access |
|---|---|---|---|---|---|---|
| Urban (n=156) | 3.67 | 0.78 | 3.89 | 0.69 | 4.25 | 4.12 |
| Suburban (n=123) | 3.29 | 0.89 | 3.68 | 0.76 | 3.78 | 3.65 |
| Rural (n=78) | 2.98 | 1.02 | 3.51 | 0.88 | 2.96 | 2.87 |
| Remote Areas (n=27) | 2.45 | 1.15 | 3.22 | 0.95 | 2.13 | 2.01 |

The infrastructure Index scores showed even larger disparities, with urban areas achieving high ratings ($M = 4.25$), whereas remote areas scored much lower ($M = 2.13$). Training Access followed similar patterns, indicating systematic inequalities in professional development opportunities across geographic contexts.

These findings highlight the critical importance of addressing infrastructure and training disparities to ensure equitable AI implementation across Indonesia's diverse educational landscapes. The large effect sizes ($\eta^2 > 0.10$) suggest that geographic location is a major factor influencing the success of AI integration.

H. *Implementation Challenges Analysis*

Table 8 identifies the most significant challenges to AI implementation as reported by the participating teachers. Infrastructure Limitations emerged as the most frequently cited challenge (75.3% of participants) with a high severity rating ($M = 4.23$). Lack of Training was the second most common challenge (69.5%) and received a high severity rating ($M = 4.15$).

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Limited Technical Support (63.8%) and Insufficient Resources (60.9%) were also frequently mentioned, indicating systemic issues with institutional support for technological integration. Interestingly, Resistance to Change was reported less commonly (51.6%) and received lower severity ratings (M = 3.45), suggesting that teachers are generally receptive to AI integration when adequate support is provided.

Table 8. Challenges and Barriers to AI Implementation

| Challenge Category | Frequency | Percentage (%) | Severity Rating (1-5) | Priority Rank |
|---|---|---|---|---|
| Infrastructure Limitations | 289 | 75.3 | 4.23 | 1 |
| Lack of Training | 267 | 69.5 | 4.15 | 2 |
| Limited Technical Support | 245 | 63.8 | 3.89 | 4 |
| Insufficient Resources | 234 | 60.9 | 3.76 | 5 |
| Resistance to Change | 198 | 51.6 | 3.45 | 8 |
| Time Constraints | 187 | 48.7 | 3.67 | 6 |
| Digital Literacy Gaps | 176 | 45.8 | 3.78 | 7 |
| Internet Connectivity Issues | 156 | 40.6 | 4.01 | 3 |

Internet Connectivity Issues, reported by only 40.6% of participants, received high severity ratings (M = 4.01), reflecting the critical importance of reliable Internet access for AI tool utilization. These findings provide clear priorities for policy intervention and resource allocation to support the successful implementation of AI.

I. *Discussion*

The findings of this study provide significant insights into the application of the AI-TPACK framework within Indonesian educational contexts, revealing both promising developments and substantial challenges. The moderate levels of AI-TPACK integration observed among participants (M = 3.29) suggest that Indonesian teachers are in the early stages of developing competencies necessary for effective AI integration, consistent with international research on technology adoption patterns in educational settings (Darmawan et al., 2024) .

The strong predictive relationship between Ai and TPACK integration and student learning autonomy (β = 0.425, p < 0.001) confirms theoretical expectations about the critical role of teacher competency in technology-enhanced learning outcomes. This relationship suggests that investments in teacher development for AI integration can yield substantial benefits for student learning, supporting the Indonesian government's emphasis on educator preparation as part of the national AI curriculum implementation strategy (Alwakid et al., 2025).

The variation in competency levels across different TPACK components reveals important patterns in professional development planning. Teachers demonstrated strong foundational knowledge in content areas (M = 4.23) and general pedagogy (M = 4.18) but showed greater challenges with technology integration components. This pattern is consistent with international research indicating that pedagogical technology integration represents a more complex competency than technological or pedagogical knowledge alone (Mulyani et al., 2025).

The significant relationship between teacher AI and TPACK competency and student learning autonomy has important theoretical and practical implications. The finding that AI integration explained 61.2% of the variance in learning autonomy suggests that AI tools, when effectively implemented by competent teachers, can substantially enhance students' capacity for self-directed learning.

The relatively high scores for Resource Utilization (M = 3.83) and self-management (M = 3.78) among the students indicate that AI tools can effectively support autonomous learning when appropriate scaffolding is provided. However, the lower scores for self-monitoring (M = 3.52) suggest that students need additional support to develop the metacognitive skills necessary for effective AI utilization. This finding aligns with research emphasizing the importance of metacognitive competencies in technology-enhanced learning environments (Sari & Dwikurnaningsih, 2025).

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The strong correlation between AI and TPACK integration and learning autonomy (r = 0.69) suggests that teacher competency in AI integration serves as a critical mediating factor in the relationship between AI tools and student outcomes. This finding supports theoretical models proposing that the educational impact of technology depends primarily on pedagogical implementation rather than technological sophistication alone (Alasadi & Baiz, 2023).

The substantial disparities observed across geographic locations highlight critical equity concerns regarding AI implementation. Urban teachers' significantly higher AI-TPACK scores (M = 3.67) compared to rural (M = 2.98) and remote area teachers (M = 2.45) reflect broader patterns of digital inequality that characterize Indonesian educational contexts. These disparities are particularly concerning, given the government's mandate for nationwide AI curriculum implementation beginning in 2025-2026 (BAİDOO-ANU & OWUSU ANSAH, 2023).

The Infrastructure Index results provide concrete evidence of the systemic challenges facing equitable AI implementation. The substantial difference between urban (M = 4.25) and remote (M = 2.13) area infrastructure indicates that successful AI integration requires significant investment in digital infrastructure development, particularly in underserved regions. This finding aligns with international research that emphasizes infrastructure as a foundational requirement for educational technology success (Bahroun et al., 2023).

The inverse relationship between teaching experience and AI-TPACK readiness presents both challenges and opportunities for professional development. Newer teachers' higher AI integration scores (M = 3.51 for less than five years of experience) suggest that recent graduates may be better prepared for technology integration, possibly reflecting enhanced pre-service preparation programs. However, lower scores among experienced teachers indicate the need for targeted professional development approaches that acknowledge the expertise and perspectives that veteran educators bring to AI integration efforts (Farrokhnia et al., 2024).

A systematic analysis of implementation challenges reveals clear priorities for policy intervention and institutional support. Infrastructure Limitations, cited by 75.3% of the participants with high severity ratings (M = 4.23), represent the most fundamental barrier to AI implementation. This finding is consistent with broader research on technology integration in developing educational contexts, where infrastructure constraints often limit the effectiveness of innovative pedagogical approaches (Kamalov et al., 2023).

The prominence of training-related challenges (69.5% reporting a Lack of Training) emphasizes the critical importance of comprehensive professional development programs. The high severity rating for training deficits (M = 4.15) suggests that teachers recognize their need for additional competency development, but lack access to appropriate learning opportunities. This finding supports international research indicating that effective technology integration requires sustained, job-embedded professional development rather than brief one-time training sessions (Mannuru et al., 2025).

Limited Technical Support (63.8%) and Insufficient Resources (60.9%) pointed to systemic institutional challenges that extend beyond individual teacher competency. These findings suggest that successful AI implementation requires coordinated institutional support including technical assistance, resource allocation, and administrative commitment. The relatively low prominence of Resistance to Change (51.6%) indicates that teachers are generally receptive to AI integration when adequate support structures are provided.

## IV. CONCLUSIONS

This study provides comprehensive empirical evidence regarding the implementation of Generative AI in Indonesian educational settings, revealing both the significant potential and substantial challenges for successful integration. This research demonstrates that teachers' AI-TPACK competency serves as a critical predictor of student learning autonomy, explaining over 61% of the variance in autonomous learning behaviors. This finding confirms the theoretical importance of teacher preparation and competency development in determining the educational impact of AI technology. The moderate levels of AI integration readiness observed among Indonesian teachers (M = 3.29) indicate that the educational system is in the early stages of AI adoption, requiring substantial support and development efforts to achieve the ambitious goals of national AI curriculum implementation. The strong foundation in content knowledge and general pedagogical competencies provides a solid base for AI integration, but significant enhancement is needed in technology-specific competencies, particularly in AI-TPACK integration skills. Geographic disparities represent a critical equity concern, with urban teachers demonstrating significantly higher readiness levels than their rural and remote counterparts. These disparities reflect broader patterns of digital inequality, which must be addressed through targeted infrastructure development and differentiated professional development approaches. The identified systematic challenges ncluding infrastructure limitations, training deficits, and inadequate technical support, provide clear priorities for policy intervention and resource allocation.

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