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The influence of technological skills and geographical conditions on elementary school teachers' readiness for implementing *DL*

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Abstract: *This study investigates the influence of technological skills and geographical conditions on elementary school teachers' pedagogical readiness to implement deep learning in Situbondo, Indonesia. Employing an explanatory quantitative design, data were obtained from 30 teachers across three geographic zones using a validated 48-item Likert-scale questionnaire. Results from regression analysis showed that both variables jointly affected pedagogical readiness ($R^2 = 0.424$; $p < 0.05$), though only technological skills had a significant partial effect. Teachers with stronger digital competence demonstrated higher readiness, regardless of infrastructural challenges, indicating that pedagogical adaptability is less constrained by geography than by digital proficiency. The findings underscore the importance of TPACK-based professional development, contextual offline learning resources, and continuous digital literacy support for teachers in under-resourced regions. This research contributes empirical evidence to promote equitable and sustainable learning opportunities in geographically diverse contexts.*

Keywords*: Technological skills, Pedagogical readiness, Deep learning, TPACK, Elementary education.*

Introduction

Digital technology has fundamentally transformed various aspects of life, including the education sector. In the era of Industry 4.0 and Society 5.0, teaching and learning can no longer rely on traditional methods alone. Teachers play a central role in integrating technology to create meaningful, contextualized learning experiences. Consequently, mastery of technological skills and the willingness to embed them into instruction have become essential (Barreto Daisyane & Orey, 2013)

One widely adopted framework for understanding twenty-first-century teacher competence is Technological Pedagogical Content Knowledge (TPACK). TPACK merges three domains-technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) enabling teachers to select instructional strategies that align with student characteristics, subject matter, and available technologies. However, (Muhaimin et al., 2019) found that many Indonesian teachers still lack sufficient TK, which constrains effective technology integration in classrooms. Recent studies also emphasize that the implementation of TPACK not only strengthens teachers' digital pedagogical capacity but also supports the development of 21st-century skills, making it increasingly relevant for elementary education in Indonesia (Handini & Mustofa, 2022).

Beyond TPACK, constructivist learning theory provides a foundational basis for technology-enhanced education. Constructivism posits that learners actively construct knowledge through hands-on experiences and social interaction. This approach aligns with digital education's emphasis on project-based, collaborative, and problem-centered learning

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(Rahmani, 2023). Technology, when thoughtfully designed, can support these experiences by promoting active engagement and reflective thinking. They (Liu et al., 2015) found that constructivist-oriented digital learning environments enhance students' critical and creative thinking skills. Similarly, (Guggemos & Seufert, 2021) emphasized that technology-based learning, when grounded in constructivist pedagogy, fosters professional growth and meaningful knowledge construction.

In geographically challenging regions, however, significant barriers persist. In Situbondo Regency, East Java, many primary schools particularly in mountainous and remote areas face limited digital infrastructure. Schools like SDN Sumberejo Gugus 8 struggle with poor internet connectivity, inadequate road access, and insufficient technological resources. These conditions directly undermine teachers' readiness to implement technology-based deep learning approaches. A national study by (Setiawati et al., 2025) similarly reported that while digital learning innovations hold potential to improve student participation, their implementation in remote Indonesian schools remains constrained by unstable infrastructure and limited teacher preparedness.

Previous studies have highlighted general obstacles to educational technology integration insufficient teacher training (Lisia et al., 2024), infrastructural deficits (Firdaus & Ritonga, 2024), and inter-regional learning outcome gaps (Ananda et al., 2025). Yet few have specifically examined how geographical context interacts with teacher technological skills to shape pedagogical readiness for deep learning, especially at the local level. (Yulianto et al., 2024) further note that Situbondo teachers encounter difficulties understanding and applying the "Merdeka Curriculum," particularly in designing interactive, technology-mediated instruction.

Accordingly, this study aims to analyze the effects of teachers' technological skills and geographical conditions on their pedagogical readiness to implement deep learning in Situbondo's elementary schools. Grounded in the TPACK framework and constructivist theory, it seeks to produce empirical mapping and offer contextualized solutions to existing gaps.

The urgency of this research is underpinned by Indonesia's commitment to Sustainable Development Goal 4 "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" and by the National Medium-Term Development Plan (Kementerian PPN/Bappenas, 2019), which prioritizes digital transformation in education. Locally, Situbondo has demonstrated initiative through digital school programs such as Google Reference Schools. However, without evidence-based, locally relevant data and policies, these initiatives risk misalignment. Findings from this study are expected to inform the Education Office, schools, and policymakers in designing localized teacher training, strengthening infrastructure, and developing offline learning materials tailored to each geographical context.

Method

This study employed a quantitative approach using an explanatory research design aimed at examining the causal relationship between the independent variables technological skills (X_1) and geographical conditions (X_2) and the dependent variable, namely teachers' pedagogical readiness (Y). This design was chosen to explore causal links among variables through inferential statistical analysis. The research was conducted from May to June 2025 in Situbondo Regency, East Java. The study site encompassed three major geographical zones: mountainous, coastal, and inland areas, each representing distinct characteristics of public elementary schools. The study population consisted of all public elementary school teachers across 17 districts in Situbondo Regency. Stratified random sampling was used based on geographical categories. From each zone (mountainous, coastal, and inland), one representative school was selected, and all teachers in the selected schools were included as respondents. The total sample comprised 30 teachers. This sample size meets the minimum requirement for ANOVA and regression testing in quantitative research and provides sufficient statistical power for educational and social science studies (Maxwell et al., 2017).

The research instrument was a 5-point Likert scale questionnaire designed to measure the variables X_1 (technological skills), X_2 (geographical conditions), and Y (teachers' pedagogical readiness). The scale ranged from 1 = Strongly Disagree to 5 = Strongly Agree. The questionnaire contained 48 items developed based on theoretical indicators for X_1 (Technological Skills) comprised 8 indicators such as the use of hardware and software for teaching; X_2 (Geographical Conditions) included 6 indicators, such as digital infrastructure availability and regional accessibility; and Y (Pedagogical Readiness) included 3 indicators= training and preparedness, student engagement, and localization of learning content. Each indicator included at least three positively and three negatively worded items. Item validity was assessed using Corrected Item-Total Correlation (valid if ≥ 0.30), while internal consistency was tested using Cronbach's Alpha, which yielded a reliability score of $\alpha = 0.837$, indicating high internal consistency. The research procedure involved several stages. In the preparation phase, research permits were obtained from the Situbondo Education Office and participating school principals. The socialization phase involved informing teachers about the study through teacher working group (KKG) forums. Questionnaire distribution was conducted both online (Google Forms) for schools with adequate internet access, and offline (printed surveys) for those in areas with limited connectivity, with responses returned by post or collected in person. Each respondent received an informed consent form outlining the purpose and procedures of the study and confirming their voluntary participation. Data quality control included ensuring at least 80% response rate per school and validating data for inconsistencies. Data were analyzed using parametric statistical techniques. The analysis steps included data cleaning include detecting missing values, outliers, and reverse coding of negative items. Assumption testing include normality was tested using the Shapiro-Wilk test (data considered normal if $p > 0.05$). Homogeneity of variance across groups was tested using Levene's Test ($p > 0.05$). Descriptive statistics include mean, standard deviation, and score distributions were calculated for each indicator.

Final validity and reliability testing include re-conducted after data cleaning. Hypothesis testing include one-way ANOVA was used to examine differences in pedagogical readiness across geographical regions. If significant, Tukey HSD post-hoc analysis was applied. Multiple regression analysis was performed to assess both simultaneous and partial effects of X_1 and X_2 on Y. The model was tested using t-tests (for partial effects), F-tests (for overall model fit), and the coefficient of determination (R^2). Findings were presented narratively and in standardized SPSS table formats. Results were interpreted in relation to prior literature and local education policy context. The study adhered to ethical research standards, including written informed consent, confidentiality of respondent identity, and no external funding or conflicts of interest. All data were securely encrypted and stored for at least two years to support audit and replication processes.

Results and Discussion

The questionnaire instrument, consisting of 48 items, demonstrated an acceptable level of validity. All items had a Corrected Item-Total Correlation ≥ 0.30, ranging from 0.301 to 0.651, indicating that each item was consistently related to the overall construct. The overall Cronbach's Alpha value was 0.837, reflecting high internal consistency. Although some items showed a potential increase in alpha if deleted, none needed to be eliminated as all met the acceptable reliability threshold ($\alpha \geq 0.70$).

The Shapiro-Wilk Normality Test showed a p-value of 0.573 (> 0.05), indicating that the data were normally distributed, thus satisfying the assumption for parametric analysis. Additionally, Levene's Test for Homogeneity of Variances produced a p-value of 0.783 (> 0.05), confirming that the variances across geographic groups were homogeneous, allowing for a valid one-way ANOVA.

Tabel 1. One-Way ANOVA (Pedagogical Readiness across Geographical Zones)

Source	Sum of Squares	df	Mean Square	F	Sig. (p)
Between Groups	2214.368	2	1107.184	1.894	0.128
Within Groups	2484.248	27	92.009		
Total	4698.616	29			

The ANOVA yielded an F-statistic of 1.894 and a p-value of 0.128 (> 0.05), indicating no significant difference in pedagogical readiness among the three geographic zones. This suggests that while geographical factors may have practical implications, they do not cause statistically significant disparities in teacher readiness across regions.

Tabel 2. Post-Hoc Tukey HSD – Mean Differences Across Regions

Group 1	Group 2	Mean Difference	p-adj	Lower Bound	Upper Bound	Signifikan
Mountain	Coastal	-15.667	0.875	-54.610	23.277	No
Mountain	Inland	-29.000	0.245	-67.943	9.943	No
Coastal	Inland	-17.667	0.792	-56.610	21.277	No

All comparisons show p-adjusted values > 0.05 and "not significant" results, reinforcing the ANOVA findings: there are no statistically significant differences in pedagogical readiness across geographical regions.

Tabel 3. Summary of Multiple Linear Regression Model

Model	R	R Square	Adjusted R Square	Std. Error of Estimate
1	0.651	0.424	0.398	7.121

Tabel 4. ANOVA for Regression

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1989.144	2	994.572	8.470	0.0018
Residual	2709.472	27	100.351		
Total	4698.616	29			

Tabel 5. Coefficients of Multiple Regression

Variabel Independen	B	Std. Error	Beta (β)	t	Sig. (p)
Constant	12.804	5.111	–	2.504	0.019
Technological Skills (X_1)	0.714	0.244	0.521	2.926	0.007 **
Geographical Conditions (X_2)	0.135	0.198	0.117	0.682	0.501

Note: $p < 0.05$ indicates statistical significance. X_1 has a significant effect on Y; X_2 does not. The R^2 value of 0.424 implies that 42.4% of the variation in pedagogical readiness can be explained by X_1 and X_2. The F-statistic of 8.470 and p = 0.0018 confirms the regression model is significant overall.

Tabel 6. Partial t-Test Results

Variable	Coefficient	t-value	p-value	Significance
Intercept (β_0)	-	-	-	-
Technological Skills (X_1)	$\beta_1 > 0$	High	**< 0.05**	Significant
Geographical Factors (X_2)	$\beta_2 \approx 0$	low	**> 0.05**	Not significant

The analysis shows that technological skills (X_1) significantly affect teachers' pedagogical readiness. This implies that the more proficient teachers are in using and integrating technology, the more prepared they are to implement deep learning strategies. This finding aligns with Ertmer & Ottenbreit-Leftwich (2010), who emphasize the critical role of technological competence in transforming pedagogy. On the other hand, geographical conditions (X_2) did not significantly influence pedagogical readiness. Despite infrastructural challenges in mountainous or remote areas, teachers demonstrated substantial pedagogical adaptability.

These findings suggest that teachers' readiness to apply deep learning approaches is more influenced by their technological competencies than by external geographical constraints. Therefore, teacher training and professional development policies should prioritize practical digital literacy enhancement, tailored to the specific access challenges in rural and underserved regions.

The research findings indicate that teachers' technological skills significantly influence their pedagogical readiness to implement deep learning approaches ($\beta_1 = 0.714$; p = 0.007), whereas geographical conditions do not exert a significant partial effect ($\beta_2 = 0.135$; p = 0.501). The regression model explains 42.4% of the variance in teachers' pedagogical readiness ($R^2 = 0.424$; F = 8.470; p = 0.0018). Meanwhile, the one-way ANOVA test confirmed that there were no significant differences in readiness across geographical zones (p = 0.128). These results align with the study by (Budhiarti et al., 2025), which found that technological proficiency facilitates the implementation of deep learning in primary classrooms, particularly in designing tasks that promote deep understanding and student reflection. Contrastingly, (Hudson et al., 2000) emphasized infrastructure as the main predictor of teacher readiness. However, this research underscores the dominant role of teachers' digital competence over geographic barriers. This is also in line with (Pettersson & Näsström, 2021), who found that technological-pedagogical competence (analogous to the TPACK framework) plays a critical role in facilitating deep learning strategies, even in contexts with limited access.

Within the TPACK framework, technological knowledge (TK) enables teachers to design activities aligned with the deep learning approach, such as problem-based learning (PBL), critical discussion, and integrated projects that require higher-order thinking (Schmidt et al., 2009). The constructivist learning theory supports this, as deep learning emphasizes students as active constructors of knowledge through analysis, synthesis, and reflection (Jonassen, 2010). The finding that teachers with higher technological competence demonstrate greater pedagogical readiness is consistent with literature that highlights the importance of digital pedagogical content knowledge (DPCK) in designing deep learning instructional scenarios (Koh et al., 2015).

In terms of professional development, this research suggests that continuous training programs based on the TPACK framework should specifically focus on deep learning strategies. For instance, schools and local education authorities could organize workshops on designing problem-based learning modules and on using collaborative digital platforms (Guggemos & Seufert, 2021). To address infrastructural limitations in remote areas, schools can develop offline learning modules rooted in the local context of Situbondo (e.x., localized case studies) to support deep learning without relying entirely on internet connectivity. In addition, technical mentoring programs should be implemented, particularly for novice teachers, with high-performing teachers (e.x., 'guru penggerak') serving as peer mentors within professional learning communities (PLCs).

This study acknowledges several limitations. First, the sample size was relatively small, consisting of only 30 primary school teachers, which may limit generalizability. Future research should replicate the study with a larger and cross-district sample. Second, the use of self-report questionnaires introduces the potential for social desirability bias. It is recommended that future studies include classroom observations or teacher portfolio analyses to triangulate the data. Third, the two-month data collection window may have been too short to capture long-term changes in teachers' readiness.

Conclusion

This study concludes that teachers' technological skills and geographical conditions jointly have a significant effect on pedagogical readiness in implementing deep learning approaches at elementary schools in Situbondo Regency. The regression analysis indicates that 42.4% of the variance in pedagogical readiness can be explained by these two variables. However, only teachers' technological skills showed a significant partial effect, while geographical challenges did not directly influence readiness. Despite the geographical constraints in Situbondo teachers demonstrated positive pedagogical adaptation, particularly when supported by adequate technological competencies. This finding underscores the high potential of improving technological skills as a primary intervention strategy to enhance deep learning quality, even in infrastructure-challenged regions. Practically, the findings emphasize the importance of continuous training programs based on the TPACK framework and constructivist theory, the provision of contextualized digital learning resources, and local government policy support. At the school level, teachers and principals must foster professional collaboration through learning communities and integrate local cultural content into innovative learning strategies. Therefore, achieving equitable education quality in regions like Situbondo requires not only improving physical infrastructure but more importantly, strengthening the digital and pedagogical capacity of teachers as the key agents of educational transformation.

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