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Are Teachers Ready to Adopt Deep Learning Pedagogy? The Role of Technology and 21st-Century Competencies Amid Educational Policy Reform

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Abstract

The transformation of national education policy during Indonesia's governmental era has led to regulatory disruptions through the rapid revocation of previous policies and swift introduction of new ones. This landscape requires teachers to possess technological proficiency as well as 21st-century competencies and pedagogical readiness to adopt innovative learning. This study examines the influence of technological knowledge and 21st-century competencies on teachers' readiness to adopt deep learning pedagogy, while also exploring perceptions of opportunities and challenges. A sequential explanatory mixed-methods design was employed, involving a survey of 802 teachers from regions of Indonesia. The instrument comprised 25 items across three variables, validated by experts, and tested with confirmatory factor analysis, which showed acceptable fit and reliability. Quantitative data were analyzed statistically, while qualitative insights came from interviews with 30 teachers and analyzed thematically. Results indicate that 21st-century competencies $(\beta = 0.639,\ R^2 = 0.432)$ exert stronger influence than technological knowledge $(\beta = 0.575,\ R^2 = 0.310)$ in shaping readiness. The integration of connecting and embedding strategies revealed personal, structural, and cultural complexities in implementing deep learning. The study recommends localized training and partnerships with professional organizations, higher education institutions, and NGOs to generate systemic support for school reform toward learning organizations.

Keywords: deep learning pedagogy; educational policy reform; teacher readiness; technological knowledge; 21st-century competencies

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1. Introduction

1.1. Background

Over the past decade, the global educational landscape has undergone systemic and multidimensional transformations. Technological disruptions, labor market dynamics, and the urgency of mastering 21st-century competencies have driven a fundamental shift in learning paradigms (Fullan et al., 2014). Education is no longer viewed merely as the transmission of static knowledge but rather as a holistic process of cultivating learners' intellectual, social, and emotional capacities. In other words, education systems are being challenged to move away from content-driven approaches and adopt reflective, collaborative, and contextual models of learning. One pedagogical response to these demands is the emergence of deep learning pedagogy, which promotes transformative learning experiences through active student participation, authentic problem-solving, and meaningful integration of technology. In this study, the term deep learning pedagogy refers to a transformative and student-centered approach to teaching and learning, and should not be confused with deep learning as used in the field of artificial intelligence.

Deep learning stems from a perceived need to engage in tasks with precision and meaningfulness, encouraging learners to apply the most suitable cognitive strategies (Tang & Biggs, 2007). According to Fullan et al. (2014), deep learning pedagogy is not solely concerned with content mastery but equally emphasizes the development of critical thinking, collaboration, creativity, and communication skills. Rather than relying on rote memorization, students are encouraged to construct meaning, make interdisciplinary connections, and solve real-world problems. Consequently, the teacher's role transforms from that of a knowledge transmitter to a facilitator, learning designer, and reflective instructional leader.

To fulfill this role effectively, teachers must possess an integrated understanding of content knowledge, pedagogical knowledge, and technological knowledge, as conceptualized in the TPACK model by Mishra and Koehler (2006). This model highlights not only the significance of each knowledge domain but also their dynamic interplay in the design of relevant, adaptive, and contextualized learning experiences (Karchmer-Klein & Konishi, 2023). Therefore, the successful implementation of deep learning approaches depends heavily on a teacher's ability to navigate the complexity of simultaneously managing pedagogy, content, and technology.

At the global level, scholars such as Grey and Morris (2024) emphasize that these transformations are reinforced by the recommendations of international organizations like the OECD and UNESCO, both of which stress the importance of embedding 21st-century competencies in education systems. These competencies include critical thinking, digital literacy, cross-cultural collaboration, effective communication, and ethical global awareness. Realizing such competencies requires learning practices that transcend conventional classroom boundaries and position students as active participants in their own learning journeys. As noted by Niyazi and Wu (2024), teacher capacity remains the foundation upon which policy-driven educational reform can translate into meaningful classroom practice.

1.2. Problem Statement

In Indonesia, national education reform has been pursued through several progressive initiatives. These include the launch of the independent curriculum, the teacher leadership program, the *Merdeka Mengajar* digital platform, and various training programs aimed at integrating digital technologies into instruction. At the policy narrative level, these reforms are aligned with global shifts toward student-centered learning, competency-based education, and technology-enhanced instruction. These approaches not only respond to contemporary challenges but also advance the goals of sustainable development in education, particularly in promoting equitable access to quality learning. In this regard, Rosário et al. (2025) underscore the transformative potential of digital innovation in supporting progress toward the Sustainable Development Goals (SDGs).

One of the key strategies currently implemented in major Indonesian cities to accelerate teacher readiness for 21st-century pedagogy is the training of trainers (ToT) program.

This initiative is designed to develop regional education leaders capable of systematically disseminating AI-based teaching practices. Complementary to this, the government has introduced technical training programs focused on strengthening STEM literacy and integrating technology into science and mathematics instruction. Although these efforts are still limited in geographical scope, they demonstrate a clear commitment to preparing teachers as central actors in innovative and deep learning ecosystems.

Nevertheless, a fundamental challenge persists in the form of policy discontinuity and implementation gaps. A notable example is the termination of the Driving School Program through Ministerial Decree No. 14/M/2025, only a few years after it had been positioned as a central pillar of educational transformation. Successive changes in ministerial leadership have often brought new curriculum reforms, introduced without a systematic evaluation of earlier initiatives. This recurring pattern of discontinuous reform fosters uncertainty among educators and frequently places teachers in a reactive position, confronting frequent changes without sufficient systemic support. This concern echoes the perspectives of Ardito and Dron (2024) and Santella (2023), who argue that teachers often experience policy turbulence with little lasting impact on actual classroom conditions.

1.3. Research Gap

At the school level, the gap between policy ambitions and actual teacher capacity is becoming increasingly apparent. For instance, Prasojo et al. (2018) found that although many teachers had completed technology-based training, the acquired competencies were rarely applied in classroom settings due to limitations in infrastructure, lack of institutional support, and school cultures that resist change (Rojak, 2024). Teachers may be able to operate digital tools, but they often lack the pedagogical insight necessary to integrate these tools in ways that foster reflective and collaborative learning.

Furthermore, Revina et al. (2023) observed that most teacher training remains overly formalistic and unidirectional, failing to cultivate the critical and reflective thinking required for deep learning. The situation is even more pronounced in remote and underdeveloped areas, where teachers face additional barriers such as poor access to digital devices, unreliable internet connectivity, and a lack of context-specific training and mentoring opportunities. These limitations continue to widen the educational quality gap between regions (Supardi & Hasanah, 2020).

Exacerbating the issue is the partial and often superficial understanding of TPACK integration among educators. Research by Bentri et al. (2022) and Istiningsih (2022) indicates that many teachers still regard technology primarily as a visual aid, rather than as a transformative tool for authentic learning. As a result, technology use frequently replicates traditional pedagogical practices in digital form, rather than enabling exploration, collaboration, and deep engagement (Adnan et al., 2024).

Meanwhile, Indonesia's below-average performance in PISA assessments, when compared to OECD countries, reflects the fact that curriculum and policy reforms have yet to produce substantial improvements in learning outcomes. This raises critical questions about the effectiveness of recent educational interventions, particularly given that 20 percent of the national budget is allocated to education, much of which is invested in teacher development and infrastructure.

1.4. Objectives

Given these conditions, there is an urgent need for deeper empirical investigation into teacher readiness to implement deep learning pedagogy. It is insufficient to simply assess how many training programs teachers have completed. Instead, it is essential to explore how technological knowledge, 21st-century competencies, and teachers' perceptions of policy reforms influence their preparedness to serve as facilitators of transformative learning. Technical deficits alone may not fully explain teachers' limitations. Underlying epistemological and institutional complexities must also be examined, as emphasized by Ramírez-Correa et al. (2025), who argue that sustainable digital transformation requires evidence-based evaluations of public policies to ensure alignment with inclusive and contextually grounded educational practices.

These realities suggest that assumptions regarding teacher readiness for deep learning approaches should not be taken at face value. A more systematic inquiry is needed into how teachers' technological proficiency, pedagogical understanding, and 21st-century competencies interact to shape their readiness. Equally important is understanding how teachers interpret the rapidly evolving policy environment, with all its associated challenges and opportunities.

2. Literature Review

2.1. Deep Learning Pedagogy and Teachers' Readiness for Innovation

The concept of deep learning in this paper is grounded in Marton and Säljö's (1976a, 1976b) distinction between surface-level processing, which relies on rote memorization, and deep-level processing, which focuses on grasping meaning, reflection, and integration of knowledge. Building on this, Biggs and Tang (2011) defined deep learning as a deep approach to learning that genuinely addresses intended outcomes through reflection, hypothesis building, and application. Deep and surface learning are not personality traits but responses to the teaching and assessment environment, which clarifies that deep learning here refers to pedagogy rather than artificial intelligence. Empirical studies reinforce this view: Baeten et al. (2010) highlight the influence of assessment and workload, Hounsell (2005) shows how deep engagement in writing constructs meaning, and Trigwell and Prosser (2004) demonstrate that student-focused teaching fosters deep learning.

The deep learning approach emphasizes meaningful cognitive engagement through conceptual understanding, reflective thinking, and the ability to transfer knowledge across contexts. This contrasts with surface learning, which focuses on mechanistic memorization (Huang et al., 2024). Deep learning encourages the integration of new information into existing cognitive schemas, resulting in the active construction of meaning (Asikainen & Gijbels, 2017). Empirical studies have demonstrated that this pedagogical approach is positively associated with higher learning outcomes and aligns with global demands for transformative and sustainable education (Dalehefte & Canrinus, 2023). However, the success of this approach is strongly influenced by teachers' readiness, given their central role in pedagogical implementation within the classroom. Teacher readiness, as outlined by Yang et al. (2022), comprises cognitive, affective, and conative dimensions. Teachers who possess a positive perception of deep learning tend to adopt inquiry-based, collaborative, and project-oriented strategies in their instructional practice. Despite this, structural barriers such as limited systemic training and a prevailing examination-driven culture continue to hinder effective implementation (Dockendorff & Zaccarelli, 2025).

2.2. The Role of Technology in Supporting Learning Transformation

In the context of 21st-century education, technology has transformed from a supplementary tool into a primary driver of pedagogical innovation. It supports deep learning by enabling critical exploration, meaningful collaboration, and personalized learning processes (Asad & Suleman, 2025). Interactive digital environments foster transformative learning experiences that transcend the physical boundaries of traditional classrooms (Mena-Guacas et al., 2025). The RDL (Readiness for Deep Learning) model focuses on assessing the extent to which teachers, students, and schools are prepared to implement deep learning pedagogy, considering personal, institutional, and contextual factors. The TRACK framework (Technology, Resources, Activities, Context, Knowledge) highlights the alignment of technological resources with pedagogical activities in contextually relevant ways. Similarly, the SAMR model (Substitution, Augmentation, Modification, Redefinition) provides a continuum to classify how technology transforms teaching and learning practices (Bicalho et al., 2023). The TPACK framework (Mishra & Koehler, 2006) indicates that meaningful technology integration occurs when teachers are able to synthesize content knowledge, pedagogical knowledge, and technological knowledge in a coherent and practical manner. Importantly, such readiness is not merely technical, but also influenced by teachers' personal values and beliefs about technology (Stumbrienė et al., 2024). Technology also enhances the reflective and social dimensions of learning by raising critical awareness of global issues and strengthening connections between learning and students' real-life contexts (Leal Filho et al., 2018). Nevertheless, structural challenges such as disparities in digital infrastructure, lack of practical training opportunities, and low levels of digital pedagogical literacy remain significant obstacles (Mena-Guacas et al., 2025). Professional development programs based on adult learning principles have proven to be essential in facilitating meaningful pedagogical change (Darling-Hammond et al., 2020). Additionally, visionary school leadership plays a strategic role in fostering an adaptive digital learning ecosystem by providing policy support and cultivating a culture of innovation (Bonfield et al., 2020; Karakose et al., 2021).

2.3. 21st-Century Competencies and Educational Policy Reform

Over the past two decades, global education reform has increasingly prioritized 21st-century competencies such as critical thinking, creativity, collaboration, and communication as core components of curriculum development (Çapan & Bedir, 2025). The P21 framework emphasizes that these competencies should be internalized through authentic, real-world learning experiences (Battelle for Kids, 2025), aligning with the deep learning paradigm that promotes active engagement in complex tasks, interdisciplinary collaboration, and socially meaningful contexts (Fullan et al., 2014). Trilling and Fadel (2009) conceptualize these four competencies, commonly referred to as the 4Cs, as the foundation of lifelong learning. Critical thinking enables informed decision-making, communication ensures clarity of ideas across multiple media, collaboration fosters teamwork across diverse contexts, and creativity drives innovation and problem-solving. In Indonesia, the Merdeka Curriculum reflects this shift; however, its implementation is challenged by a disconnect between policy and classroom practice (Sarkio et al., 2025; Bayeni & Bhengu, 2018). Teachers often face bureaucratic constraints, limited resources, and performance pressures that hinder the adoption of innovative pedagogy, while their responses to policy are shaped by professional beliefs, experiences, and available support (Smit, 2005). In addition to measurable factors like technological knowledge and mastery of 21st-century competencies, teachers' readiness to adopt deep learning is also influenced by their perceptions and school context (Reinius et al., 2024). OECD (2019) complements this perspective by framing 21st-century competencies as a balance between cognitive, social-emotional, and civic dimensions. This broader view underscores that educational reform is not only aimed at producing skilled workers but also at cultivating responsible global citizens who are able to participate actively in inclusive and democratic societies.

This synthesis informs the development of the research questions and hypotheses presented in Section 2.4. Based on the literature reviewed in Sections 2.1–2.3, Figure 1 illustrates the conceptual framework of this study, depicting the hypothesised relationships between technological knowledge, 21st-century competencies, and teachers' readiness to adopt deep learning pedagogy within the context of educational policy reform.

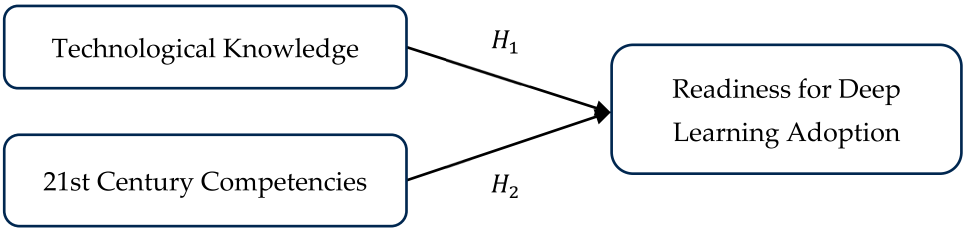

Figure 1. Conceptual framework of the study.

2.4. Research Questions and Hypotheses

Based on the research background, conceptual framework, and theoretical foundations, the following research questions and hypotheses are proposed:

Research Questions:

- To what extent does teachers' technological knowledge influence their readiness to adopt deep learning pedagogy?
- To what extent do 21st-century competencies contribute to teachers' readiness to adopt deep learning pedagogy?
- How do teachers perceive the opportunities and challenges in integrating deep learning pedagogy amid ongoing educational policy reforms?

Hypotheses:

H_1. *Teachers' technological knowledge has a positive and statistically significant influence on their readiness to adopt deep learning pedagogy.*

H_2. *Teachers' 21st-century competencies positively and significantly contribute to their readiness to adopt deep learning pedagogy.*

3. Materials and Methods

This study employed a mixed-methods approach using a sequential explanatory design, as formulated by Creswell and Clark (2018). This design was chosen to address the complexity of teacher readiness in adopting deep learning pedagogy, taking into account the integration of technology and 21st-century competencies within the context of ongoing national education policy reform. This strategy facilitates a more nuanced exploration of the relationship between macro-level policy and micro-level implementation by combining quantitative data with qualitative elaboration, thereby enhancing the validity of findings through methodological triangulation. The sequential explanatory design is considered appropriate for investigating educational dynamics that involve structural, personal, and pedagogical dimensions simultaneously. In line with Creswell and Clark (2018), this approach is effective when researchers seek to explore the meanings behind quantitative trends through participants' narratives. This model has been widely applied in contemporary educational research on teacher readiness and policy change, as demonstrated in studies by Dankyi et al. (2024), Nandani and Raturi (2024), and Shambare and Jita (2024), underscoring its effectiveness in capturing the complexity of educational practices across diverse contexts.

3.1. Quantitative Phase

Quantitative data were collected from 802 teachers who voluntarily completed an anonymous questionnaire, either online or in person. The respondents represented a broad range of subjects across primary, junior high, and senior high school levels. A non-probability convenience sampling technique was used, considering accessibility and teacher engagement in professional development programs. This approach was deemed suitable for reaching a large number of respondents efficiently and is commonly applied in exploratory educational research (Soriano-Alcantara et al., 2024).

To ensure sample adequacy, the minimum sample size was calculated using Cochran's formula (Cochran, 1977) with a 95% confidence level, a 5% margin of error, and an assumed population proportion of $p = 0.5$. Based on the teacher population of approximately 4.21 million in Indonesia, this produced a minimum requirement of 385 respondents. The final sample of 802 teachers, therefore, exceeded this threshold, enhancing statistical power and representativeness within the constraints of convenience sampling. The demographic characteristics of the respondents are summarized in Table 1.

Table 1. Frequency distribution of respondent characteristics.

Variable	Categories	Count	% of Total
Gender	Female	407	50.7%
	Male	395	49.3%
Employment status	Contract teacher (CT)	341	42.5%
	Government Teacher (GT)	271	33.8%
	Government employee with contract (GCT)	190	23.7%
School level	Junior high school	176	21.9%
	Primary school	197	24.6%
	Senior high school	429	53.5%

The quantitative data were collected through questionnaire distribution targeting teachers at various levels of formal education in Indonesia. The distribution process was carried out both online and offline, utilizing professional teacher networks such as WhatsApp groups and teacher associations. The instrument was developed based on three theoretically and empirically grounded constructs: technological knowledge (TK), 21st century competencies (21CC), and readiness for deep learning adoption (RDLA). Each construct was operationalized from established frameworks. TK items were adapted from the TPACK model (Mishra & Koehler, 2006); 21CC was derived from the Framework for 21st Century Learning (Battelle for Kids, 2025) and the works of Trilling and Fadel (2009); while RDLA combined elements from New Pedagogies for Deep Learning (Fullan et al., 2014) and the Technology Readiness Index (Parasuraman, 2000).

The instrument consisted of 25 items measured on a four-point Likert scale, designed to capture respondents' levels of agreement with each statement. The four-point scale was intentionally selected to minimize central tendency bias, which can hinder the accurate assessment of attitudes or perceptions (Savolainen et al., 2022). The items were distributed across three constructs, with eight items addressing TK, eight items targeting 21CC, and nine items related to RDLA. Example items include statements such as "I am able to select appropriate digital tools for various learning activities" for TK, "I use collaborative methods to help students work effectively in teams" for 21CC, and "I feel prepared to change my teaching strategies to support deep learning" for RDLA. All items were developed based on theoretical indicators grounded in primary literature and were contextualized to reflect the Indonesian educational environment. To ensure validity, content review was conducted by four domain experts specializing in instructional methodology, educational technology, education policy, and human resource development.

Construct validity was assessed through confirmatory factor analysis (CFA) applied to a three-factor model: TK, 21CC, and RDLA. The analysis was performed using the lavaan package within Jamovi version 2.6.4.4 (Rosseel et al., 2023). The CFA results indicated an acceptable model fit (Table 2), with RMSEA = 0.041 and SRMR = 0.044. Although the

CFI (0.867) and TLI (0.853) values were slightly below the ideal threshold of 0.90, the model was retained, given that most indicators met the recommended criteria. The Chi-square statistic $(\chi^2 = 711,\ df = 272,\ p < 0.001)$ was interpreted cautiously, considering its sensitivity to large sample sizes. Based on both theoretical rationale and statistical evidence, the construct structure was maintained without model modification.

Table 2. CFA model fit indices.

χ^2	df	p	CFI	TLI	SRMR	RMSEA	90% CI Lower	90% CI Upper	AIC	BIC
711	272	<0.001	0.867	0.853	0.0414	0.0449	0.0408	0.0489	33,255	33,621

Internal reliability was measured using Cronbach's Alpha (α) and McDonald's Omega (ω). Reliability coefficients of α and $\omega \geq 0.70$ were considered acceptable indicators of internal consistency (Trabelsi et al., 2024). All constructs demonstrated adequate reliability, as shown in Table 3.

Table 3. Instrument reliability statistics by variable.

Variable	Mean	SD	Item-Rest Correlation	Cronbach's α	McDonald's ω
TK	3.16	0.314	0.620	0.793	0.793
21CC	3.12	0.334	0.698	0.715	0.715
RDLA	3.11	0.324	0.686	0.727	0.728

The Cronbach's alpha values above 0.70 indicate strong internal consistency across all constructs, while the comparable omega values further affirm score reliability. The analysis was conducted using the Reliability module in Jamovi, which implements functions from the R psych package (Revelle, 2023; The jamovi project, 2024). Quantitative data were analyzed using Jamovi version 2.6.4.4 (The jamovi project, 2024). The analysis included descriptive statistics, internal reliability testing (Cronbach's Alpha), and confirmatory factor analysis (CFA) for construct validity. To answer the first and second research questions, linear regression was used to examine the contribution of TK and 21CC to RDLA.

3.2. Qualitative Phase

The qualitative phase of this study involved 30 teachers selected through purposive sampling. This approach ensured that all participants were directly relevant to the research focus, which centered on teachers' readiness and interpretations regarding technology-integrated instruction and deep learning-oriented educational policies. The inclusion criteria for participant selection consisted of four main points: (1) demonstrable ability in using educational technology; (2) employment status as a contract teacher, government teacher, or government contract teacher; (3) experience in participating in professional development training, and (4) voluntary consent to engage in in-depth interviews.

Participants were drawn from various regions across Indonesia, with a predominant representation from eastern provinces such as West Nusa Tenggara, East Nusa Tenggara, Kalimantan, and Jambi. They taught across different educational levels, from primary to senior high school, thus reflecting the diversity of positions and challenges within the national education context. To illustrate this diversity, several representative profiles can be highlighted. For example, Resnick and George were primary school teachers from West Nusa Tenggara with government teacher (GT) status, while Downes, also from West Nusa Tenggara, served as a senior high school teacher with government contract (GCT) status. From West Kalimantan, Laurillard represented junior high school with GCT status, whereas in Jambi Province, Puentedura (senior high, GT) and Diana (junior high, GCT) provided contrasting perspectives within the same region. Meanwhile, Hattie (primary school, GCT), Kukuls (junior high, GT), and Stephen (primary school, GCT) came from East Nusa Tenggara, complemented by Marcia (senior high, GT) from South Sulawesi. Collectively, these profiles underscore the variation in geographic background, school level, and employment status, while data from all 30 informants were included in the thematic analysis. In line with ethical standards and prior agreements with participants, complete identities and individual profiles are not disclosed.

Qualitative data were collected to reinforce and deepen the quantitative findings, particularly regarding teachers' perceptions of the opportunities and challenges in implementing deep learning in the context of national education policy changes. Interviews were conducted online via zoom, google meet, and phone calls, with each session lasting approximately 30 to 40 min. Qualitative participants were purposively selected from the pool of quantitative respondents based on variation in RDLA scores, ensuring a representative range of perspectives and experiences.

A semi-structured interview guide was developed, and thematic analysis was conducted by referring to the conceptual framework constructed during the quantitative phase. The key areas of exploration included understanding of deep learning concepts, personal and institutional readiness, integration of technology in teaching, perceptions of educational policies, and challenges of implementation at classroom and school levels.

Through the triangulation of methods and data sources, the study provides a comprehensive portrayal of teachers' readiness in adopting deep learning approaches in response to the national education paradigm shift that increasingly emphasizes collaboration, contextualization, and pedagogical innovation.

Thematic analysis was conducted following the six-phase framework proposed by Braun and Clarke (2006). Codes were inductively developed from verbatim transcripts and were subsequently consolidated into key themes reflecting teachers' perceptions of deep learning, their personal and institutional readiness, and their interpretations of national education policies. The validity of the qualitative analysis was supported through peer debriefing with two experts in education policy and qualitative methods, as well as member checking with selected participants.

3.3. Data Integration Strategy

Data integration in this mixed methods design employed the connecting and embedding strategy as outlined by Creswell and Clark (2018). This process consisted of: (1) connecting, in which quantitative results informed the selection criteria for interview participants, particularly based on variation in RDLA scores, and (2) embedding, in which the interview guide was designed based on quantitative patterns that required further exploration from a qualitative perspective. These patterns included underlying reasons behind high or low levels of teacher readiness, and perceptions of contextual policy factors. The integrated findings are presented through a joint display matrix that aligns numerical data with narrative excerpts to illustrate how qualitative insights support, explain, or elaborate on the statistical results.

4. Results

Descriptive analysis was conducted to illustrate response characteristics across the three main constructs: technological knowledge (TK), 21st century competencies (21CC), and readiness for deep learning adoption (RDLA). All three constructs yielded mean scores above 3.10 on a 4-point Likert scale, indicating a relatively high level of perception among respondents. Skewness and kurtosis values were within the acceptable range (±1), suggesting an approximately symmetric distribution. However, the Shapiro–Wilk test produced p-values below 0.05, indicating deviation from normality. The descriptive statistics of these constructs are presented in Table 4.

Table 4. Descriptive statistics of study constructs.

Construct	*N*	*Mean*	*SD*	*Skewness*	*Kurtosis*	*Shapiro−Wilk (p)*
Technological knowledge	802	3.16	0.314	−0.16	0.479	<0.001
21st Century competencies	802	3.12	0.334	−0.01	0.465	<0.001
Readiness for deep learning adoption	802	3.11	0.324	0.01	0.281	<0.001

4.1. The Effect of Technological Knowledge on Readiness for Deep Learning Adoption

A linear regression analysis was conducted to examine the effect of TK on RDLA. The regression model was statistically significant, $F(1,\ 800)\ =\ 359.00,\ p < 0.001$, with a coefficient of determination of $R^2\ =\ 0.310$. This indicates that 31% of the variance in teacher readiness for deep learning can be explained by their technological knowledge. The model yielded an Adjusted R^2 of 0.309 with a Root Mean Square Error (RMSE) of 0.269, reflecting satisfactory predictive precision. The Durbin–Watson statistic was 1.67, suggesting no serious autocorrelation, while the Shapiro–Wilk test produced $W = 0.995,\ p = 0.018$, showing only minor deviation from normality, which remains acceptable in large samples. Multicollinearity was not an issue (VIF = 1.00; Tolerance = 1.00). The regression coefficient confirmed TK as a positive and significant predictor of RDLA $(\beta = 0.575,\ SE = 0.030,\ t = 19.00,\ p < 0.001)$, implying that a one-unit increase in TK is associated with a 0.575-point increase in RDLA scores.

These findings confirm that technological proficiency is a critical component in supporting teachers' readiness to transform instructional practices through deep learning approaches. The substantial effect size suggests that technological literacy is not merely a complementary skill but a foundational prerequisite in the implementation of 21st-century, competency-based learning. Therefore, strategic investment in teacher training on instructional technology should be prioritized within the broader agenda of digital education reform. These results support Hypothesis 1 (H_1), which posits that technological knowledge has a positive and significant influence on teachers' readiness to adopt deep learning.

4.2. The Effect of 21st Century Competencies on Readiness for Deep Learning Adoption

Linear regression was also conducted to assess the effect of 21CC on RDLA. The model yielded statistically significant results, $F(1,\ 800) = 609.00,\ p < 0.001$, with an R^2 value of 0.432. This indicates that 43.2% of the variation in teacher readiness can be attributed to their level of 21CC. The model presented an Adjusted R^2 of 0.431 with RMSE = 0.244, indicating high predictive accuracy. The Durbin–Watson statistic was 1.68, showing no meaningful autocorrelation, while the Shapiro–Wilk test $(W = 0.997,\ p = 0.166)$ confirmed normality of residuals. Multicollinearity was absent (VIF = 1.00; Tolerance = 1.00). The regression coefficient revealed that 21CC is a significant and positive predictor of RDLA $(\beta = 0.639,\ SE = 0.0259,\ t = 24.70,\ p < 0.001)$, meaning that for every one-unit increase in 21CC, the RDLA score increases by 0.639 points.

These findings reinforce the position that 21CC are a key determinant of teacher readiness to implement deep learning. The strength of the predictive contribution $\left(R^2 = 0.432\right)$ indicates that mastery of skills such as critical thinking, collaboration, communication, and creativity not only supports but actively drives pedagogical readiness in transformative learning environments.

The strong and significant impact of 21CC implies that capacity-building efforts must extend beyond technological aspects to also encompass the development of generic 21st-century competencies as the foundation of deep learning practices. Hence, these results support Hypothesis 2 (H_2), which states that 21st Century Competencies significantly contribute to teacher readiness for adopting deep learning approaches.

4.3. Teachers' Perceptions of Opportunities and Barriers in Implementing Deep Learning Amid Policy Dynamics

Amid the ongoing shifts in national education policy, teachers across levels and regions expressed common responses regarding the opportunities and obstacles in internalizing deep learning. While the approach was regarded as ideal, it remained distant from daily practice due to persistent structural and cultural constraints. Resnick noted that curricular autonomy had not been fully realized in classroom settings, as reporting formats continued to tether them to traditional instructional patterns. Laurillard echoed this sentiment, suggesting that the "freedom to learn" discourse is constrained in practice by rigid administrative procedures. Attempts to implement collaborative or project-based approaches were often unsupported. Puentedura and Diana indicated that learning communities were largely ceremonial and lacked reflective function. Pedagogical innovations were frequently misunderstood as policy violations.

Issues of access were especially pronounced in underdeveloped and remote areas. Kukuls and Stephen highlighted that training rarely reached their regions, and limited digital infrastructure rendered technological integration rhetorical rather than practical. These realities hindered the internalization of 21st-century pedagogy, which emphasizes exploration, collaboration, and reflective thinking. Some teachers reported being capable of using basic tools such as PowerPoint or quiz applications but lacked understanding of how these tools could foster deep learning. Marcia explained that her online classroom did not yet incorporate systematic, reflective and critical components.

Despite these challenges, teachers expressed a persistent desire to evolve. However, frequent policy shifts have left many disoriented. Downes summarized this tension by stating: "we want to change, but if the rules and direction keep shifting, we begin to wonder: for whom are we changing?"

To strengthen transparency and reliability, the qualitative findings are summarized in Table 5, which provides the codebook of themes, sub-themes, and illustrative codes generated through Braun and Clarke's thematic analysis.

The themes identified through the qualitative analysis were further connected with the quantitative results using a joint display strategy. Table 6 presents this integration, aligning statistical findings with representative teacher quotes and their interpretive implications.

Table 5. Codebook of themes, sub-themes, and quotes.

Theme	Sub-Theme	Quote
Structural and Cultural Constraints	Limited curricular autonomy	"Curricular autonomy had not been fully realized in classroom settings." (Resnick)
	Rigid administrative procedures	"Freedom to learn is constrained in practice by rigid administrative procedures." (Laurillard)
	Lack of support for collaborative approaches	"Attempts to implement collaborative or project-based approaches were often unsupported." (Diana)
	Ceremonial learning communities	"Learning communities were largely ceremonial and lacked reflective function." (Puentedura)
Access and Infrastructure Gaps	Unequal access to training	"Training rarely reached our regions." (Kukuls, Stephen)
	Limited digital infrastructure	"Technological integration was rhetorical rather than practical." (Stephen)

Table 5. *Cont.*

Theme	Sub-Theme	Quote
	Basic but limited technology use	"I can use PowerPoint or quiz apps, but I do not yet understand how these tools foster deep learning." (Marcia)
Pedagogical Readiness Challenges	Lack of reflective and critical practice	"My online classroom did not yet incorporate systematic reflective and critical components." (Marcia)
Policy and Reform Dynamics	Frequent policy shifts causing confusion	"We want to change, but if the rules and direction keep shifting, we begin to wonder: for whom are we changing?" (Downes)
	Misinterpretation of innovation as violation	"Pedagogical innovations were frequently misunderstood as policy violations." (George)

Table 6. Joint display matrix—integration of quantitative and qualitative findings.

Key Theme	Quantitative Basis	Narrative Quote	Integrative Interpretation
21CC as a critical readiness factor	$\beta = 0.639$; $R^2 = 0.432$; $p < 0.001$	"I understand the technology, but it's hard to combine it with student collaboration."—Diana	21st-century competencies are the strongest predictor of readiness. However, difficulties in internalizing reflective and collaborative values remain.
TPACK as technical, not pedagogical	$\beta = 0.575$; $R^2 = 0.310$; $p < 0.001$	"I can use slides, but is that really deep learning? I'm not sure."—Puentedura	Teachers interpret TPACK mainly as technical support, not as a reflective pedagogical framework.
Unstable and confusing education policies	—	"We just finished training for one curriculum, and now it's already changed."—Hattie	Policy volatility creates confusion at the implementation level, hindering consistent innovation.
Digital access inequality and infrastructure gaps	Not directly quantifiable	"Internet often goes down. How can we use technology if access is unreliable?"—Kukuls	Qualitative data highlight digital divides not captured in surveys. These are major obstacles to deep learning in remote areas.
Optimism and belief in learning transformation	RDLA Mean = 3.11	"If implemented properly, students will be more engaged and understand concepts better."—Marcia	Teachers maintain strong belief in deep learning potential. This optimism forms a foundation for policy alignment and reflective training support.

These findings suggest that while teachers possess individual readiness and foundational understanding of deep learning principles (as aligned with the quantitative results), structural and institutional realities have yet to support a sustainable ecosystem for pedagogical transformation. Policy fluctuations, limited reflective space, and access disparities emerge as persistent challenges to the actualization of deep learning practices.

5. Discussion

The findings of this study indicate that teachers' readiness to adopt a deep learning approach is not determined by a single factor, but rather by a complex interaction between technological knowledge (TK), 21st century competencies (21CC), and the surrounding policy and institutional context. Statistically, both TK and 21CC significantly contribute to teacher readiness. However, in relative terms, 21CC exerts a more dominant influence.

The positive contribution of TK to teacher readiness aligns with prior studies emphasizing that technological proficiency is a critical element in supporting pedagogical innovation (Stumbrienė et al., 2024). The TPACK model considers TK a foundational component in the integration of technology into teaching and learning (Luik et al., 2024; Nilsson, 2024), which serves as a prerequisite for the emergence of deep learning-based innovations. Nevertheless, this study reveals that teachers' mastery of TK tends to be procedural and operational rather than conceptual. While many teachers are adept at using educational tools such as PowerPoint, Google Classroom, or Kahoot, they often encounter difficulties in connecting these tools with the essential dimensions of deep learning, including critical thinking, reflection, and meaningful problem-solving (Dogan & Gogus, 2025).

This supports critiques of technocentric approaches in teacher training, which often treat technology as an end in itself instead of as a pedagogical medium (McGarr, 2024). The use of technology in deep learning contexts is not limited to the adoption of tools; it also requires the teacher's ability to reframe learning as a reflective, inquiry-based process oriented toward the transfer of meaning (Fullan et al., 2014). Thus, the role of TK in shaping teacher readiness is conditional. While significant, its impact depends heavily on how teachers interpret and integrate technology within pedagogical practices.

21st-century competencies have a more substantial influence on teacher readiness compared to TK. This finding reinforces previous research by Rahimi and Oh (2024) and Nikkola et al. (2024), which underscores the importance of critical thinking, creativity, collaboration, and communication in modern educational settings. In the context of deep learning, these competencies are not merely learning objectives. They also serve as epistemic assets that enable teachers to design autonomous and transformative learning experiences (Sliwka et al., 2024).

However, a significant gap remains between teachers' declarative understanding of 21CC and their ability to implement these competencies in practice. Teachers involved in this study showed awareness of the importance of 21CC, yet struggled to translate them into tangible pedagogical strategies. This is consistent with Silverman et al. (2024), who assert that the transformation of teacher competencies requires supportive work environments, such as collaborative cultures, distributed leadership, and sustained professional learning opportunities. Without such supportive ecosystems, 21CC remain individual assets rather than collective capacities, and, therefore, have limited potential to drive instructional innovation grounded in deeper meaning.

Furthermore, teachers' perceptions of opportunities and challenges reveal a paradoxical situation. On the one hand, teachers recognize the urgency and relevance of deep learning. On the other hand, they operate within policy and institutional ecosystems that are not yet conducive to its implementation. Curriculum reforms that emphasize differentiation, character education, and learner autonomy, such as the *Kurikulum Merdeka*, have not been fully translated into school-level practices. Teachers continue to face burdens from administrative tasks, time constraints, and the pressure to meet quantifiable learning outcomes (Tatik et al., 2025).

From the perspective of policy enactment theory, educational policies are not implemented in a linear fashion. Instead, they are continually reinterpreted by practitioners based on their context, available resources, and professional values (Hay, 2025; Imants & Van der Wal, 2020). Teachers in Indonesia often face structural pressures from a transactional education bureaucracy, which can be at odds with the transformative pedagogical values foundational to deep learning. These tensions are compounded by geographic and digital disparities. Teachers in underdeveloped and remote regions report limited access to the internet, inadequate training, and professional isolation, making the adoption of deep learning feasible only in settings where strong social and technological capital exists (Bentri et al., 2022).

These findings challenge individualistic and technical views of teacher readiness, reframing it as a social construct shaped by institutional, epistemic, and policy dynamics (Darling-Hammond et al., 2020; Mena-Guacas et al., 2025). From a professional ecology perspective, readiness emerges through the interplay of teacher agency, institutional structures, and policy visions. This highlights the need for multi-level reform in teacher development, where training prioritizes reflective, collaborative, and practice-based approaches over content delivery (Darling-Hammond et al., 2020). Affirmative policies are also essential to support teachers in disadvantaged areas, including synchronous online training, digital infrastructure, and interregional mentoring. Additionally, schools must be repositioned as learning organizations that foster experimentation, collective reflection, and teacher innovation.

Similar challenges have been documented internationally. In Ghana, curriculum reform exposed the need for stronger institutional support to bridge policy expectations with classroom realities, particularly in relation to technology and pedagogy (Abedi, 2024a, 2024b). Comparable issues emerged in China and Vietnam, where teachers expressed a demand for ICT training but faced personal, institutional, and technological constraints (Hazzan-Bishara et al., 2025; Moradi, 2025). In India, professional development initiatives were introduced to support technology integration (Panakaje et al., 2024), while in Israel and Thailand, teachers struggled to adapt to rapid curricular reforms and to align with national standards, often due to limited pedagogical preparation (Assalihee et al., 2024; Bitar & Davidovich, 2024). Similar patterns were observed in Ethiopia, where teachers understood the importance of 21st-century competencies but lacked the training and resources to implement them (Mengiste, 2025), and in digital learning contexts, where success was found to depend not only on teacher competence but also on institutional and infrastructural support (Zhou et al., 2024). Collectively, these findings indicate that teacher readiness for deep learning pedagogy is not unique to Indonesia but represents a wider global challenge in aligning policy reforms with sustainable pedagogical transformation.

Thus, this study underscores that teacher readiness for adopting deep learning pedagogy should be understood as a global issue that demands cross-national attention. The success of education reforms depends not only on policy design but also on the alignment of teacher capacity, institutional support, and professional cultures that foster sustainable pedagogical transformation.

6. Limitations and Future Research

This study has several methodological limitations. First, the use of convenience sampling facilitated broad participation but restricted the representativeness of findings across all Indonesian teachers. Second, the cross-sectional design provides only a single-time snapshot, limiting the analysis of how readiness evolves alongside continuing policy reforms. Third, the qualitative phase involved a relatively small number of participants from selected regions, which may not fully capture the heterogeneity of teacher experiences nationwide. Finally, the reliance on online survey distribution, while practical, may have introduced a degree of response bias toward more digitally literate teachers.

Future research should therefore consider employing probability-based sampling strategies and longitudinal designs to provide a more dynamic understanding of teacher readiness. A more in-depth analytical approach, such as constructivist Grounded Theory, could enrich insights into how teachers construct meaning about readiness for deep learning pedagogy. In addition, the role of school leadership deserves greater emphasis. Principals should be positioned as frontline actors in initiating and sustaining the use of technology and AI in schools, ensuring that even in contexts with infrastructural or institutional constraints, teachers are not left behind. Comparative studies across regions and international contexts would further broaden the understanding of deep learning pedagogy within diverse educational ecosystems.

7. Conclusions

Teachers' readiness to adopt deep learning approaches emerges as a complex interplay between technological proficiency, 21st-century competencies, and adaptive capacity in response to evolving educational policy dynamics. The findings of this study affirm that digital literacy alone is insufficient without the presence of reflective and collaborative competencies that foster the internalization of meaningful pedagogy. Furthermore, this research reinforces the discourse on teacher readiness by underscoring the critical role of a consistent and supportive institutional ecosystem as a foundational condition for the successful transformation toward deep learning practices. Accordingly, this study contributes theoretically by strengthening the integrative framework between TPACK and 21st-century competencies within the broader context of educational reform, while also providing empirical grounding for the design of teacher training programs and the formulation of more responsive, deep learning–oriented education policies.

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