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Learning Quality in Deep Learning: Transformational Leadership, Digital Technology, and Pedagogical Practices

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Abstract

Research on deep learning in elementary education has largely discussed school leadership, technology use, and pedagogy in separate strands, leaving limited evidence on how the three operate together within the same school context. This study aims to examine the individual and joint relationships of transformational leadership, digital technology use, and pedagogical practices with learning quality in deep learning implementation. A quantitative correlational survey involved 137 teachers selected through proportionate stratified random sampling from 420 teachers in 59 public and private elementary schools in Bulakamba District, Brebes Regency, Indonesia. Data were collected with Likert-type questionnaires and analyzed using descriptive statistics, Pearson correlations, simple regression, and multiple linear regression. The three predictors were positively correlated with learning quality ($r = .509$-$.547$, all $p < .001$). The OLS model explained 36.6% of the variance (adjusted $R^2 = .366$). Because the Glejser test indicated heteroscedasticity for digital technology use and pedagogical practices, final partial inference used HC3 robust standard errors. The HC3 robust joint test remained significant, $F(3, 133) = 19.058$, $p < .001$. Transformational leadership remained significant ($B = .235$, robust $SE = .096$, $p = .016$), whereas digital technology use ($B = .385$, robust $SE = .222$, $p = .085$) and pedagogical practices ($B = .351$, robust $SE = .217$, $p = .108$) did not reach the .05 level after correction. The findings identify leadership as the clearest independent predictor while positioning technology and pedagogy as complementary elements that remain positively associated with learning quality at the bivariate level.

Keywords

Deep learning; Digital technology; Learning quality; Pedagogical practices; Transformational leadership

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INTRODUCTION

In this article, deep learning refers to a pedagogical approach rather than to artificial intelligence. It brings together meaningful understanding, mindful engagement, and enjoyable learning experiences. Andayanie et al. (2025) explain that deep learning should connect subject matter with learners' experiences while creating space for reflection and active participation. Evidence from elementary education also shows that meaningful, mindful, and joyful principles can be enacted through contextual, reflective, and positive learning experiences (Widyastuti et al., 2025). Kurnianingsih et al. (2026) emphasize that these principles should not be treated as separate techniques. Rosyidah et al. (2026) likewise position them as integrated elements that should reinforce one another within the learning experience.

For learning to become genuinely deep, classroom activity needs to move beyond content delivery and provide students with opportunities to reason, discuss, solve problems, and produce meaningful work. Bremner et al. (2022) show that learner-centred pedagogy can generate outcomes beyond academic attainment, although implementation quality is crucial. Zhang and Ma (2023) report positive effects of project-based learning on learning outcomes and twenty-first-century skills. Wijnia et al. (2024) likewise show that problem-, project-, and case-based learning can support motivation when tasks and teacher support are well designed. Setyowati and Utami (2025) report promising results from deliberately designed learning activities that develop higher-order thinking in Indonesian elementary education. Qomariyah et al. (2026) also show that project activities can support students' engagement in learning.

Such learning quality is not determined by classroom teaching alone. School leadership shapes direction, support, and working conditions that enable teachers to improve their practice. Özdemir et al. (2024) show that links between school leadership and student outcomes often operate through organizational and instructional conditions. Tan et al. (2024) similarly find that leadership practices that strengthen teacher capacity and instructional management are associated with student outcomes. Sun et al. (2024) demonstrate that leadership can shape a productive academic press and a school-wide focus on learning. Richardson and Khawaja (2025) further identify leadership competencies as important for building more learner-centred and personalized environments. Transformational leadership is therefore particularly relevant when schools are changing how teaching and learning are organized.

Research focused on teacher professional learning helps explain these pathways. Thien et al. (2024) find that learning-centred leadership can foster teacher professional learning through mastery goals and self-efficacy. Huang et al. (2023) show that principal leadership is related to professional learning at both school and teacher levels. He et al. (2024) emphasize the role of instructional leadership in teacher professional development. Huang et al. (2024) identify teacher professional learning as an important mechanism in explaining differences in instructional quality. Broader evidence indicates that the strength of leadership–achievement relationships depends on the conceptual model and analytical approach used (Shen & Wu, 2025). In Indonesia, Utami et al. (2024) report a relationship between principal transformational leadership, teacher performance, and learning quality.

Changes in learning are also increasingly dependent on teachers' ability to use technology purposefully. Bentri et al. (2022) show that elementary teachers' digital pedagogical competence in Indonesia is supported by professional learning and the work environment. Wohlfart and Wagner (2023) argue that educational digitalization should not be reduced to device use; it requires teachers to select and integrate technology for clear learning purposes. Heine et al. (2023) further show that professional digital competence includes evaluating, selecting, developing, and using digital resources. Sofyan et al. (2023) demonstrate the importance of examining the relationship among technological, pedagogical, and content knowledge and internet use among elementary teachers. Claro et al. (2024) show considerable variation in how teacher digital competence is defined and measured. Petko et al. (2025) therefore emphasize that the quality of technology-supported practice is more informative than device-use frequency alone.

The same issue is visible in elementary-school practice. Nisak and Rofi'ah (2023) identify practical difficulties that teachers face when using digital learning media. By contrast, Susanti et al. (2025) show that well-designed digital media can support student motivation, creativity, and understanding. Roudhoh et al. (2026) report that teachers' digital competence is related to the effectiveness of digital learning media. Hase and Kuhl (2024) add that data from digital platforms become useful when teachers use them to adapt instruction. Masoumi and Noroozi (2025) emphasize that digital competence grows through experience and adequate support. Ma and Ismail (2025) also highlight the importance of workplace context in the development of digital competence. Technology should therefore be treated as part of pedagogy rather than as an isolated factor.

Previous studies have commonly examined leadership, technology use, or pedagogy

separately. In practice, however, deep learning develops within one school ecosystem: leaders establish direction and support, teachers choose and use technology, and learning quality is realized through classroom practice. Feri (2025) argues that deep learning requires both a shift in perspective and greater teacher readiness. Nurrani and Herlambang (2025) place active participation and mindful learning at the center of the approach. Siregar et al. (2025) show that deep-learning design requires alignment among context, cognitive activity, and enjoyable learning experiences. Despite these developments, evidence remains limited on how transformational leadership, digital technology use, and pedagogical practices operate together within the same elementary-school model. Addressing this gap, the present study aims to examine their individual and joint relationships with learning quality in deep learning implementation in Bulakamba District.

METHOD

This study used a quantitative correlational survey design. It was conducted in public and private elementary schools in Bulakamba District, Brebes Regency, Central Java, from December 2025 to May 2026. The population comprised 420 teachers across 59 schools, consisting of 411 teachers in 57 public schools and 9 teachers in 2 private schools. Sample size was determined using the Slovin formula with a 7% margin of error: $n = 420/[1 + 420(0.07^2)] = 137.34$, which was rounded to 137 teachers. Proportionate stratified random sampling treated each school as a stratum. The allocation for each school followed $n_i = (N_i/N) \times n$, with a largest-remainder adjustment used to keep the final sample at exactly 137. This procedure produced 134 teachers from public schools (97.81%) and 3 teachers from private schools (2.19%), closely reflecting the population composition.

Data were collected using Likert-type questionnaires. Transformational leadership (X1) measured teachers' perceptions of principals' direction setting, motivation, intellectual stimulation, role modelling, and individualized support. Digital technology use (X2) covered digital literacy, the use of devices and platforms, and the integration of digital media into instruction. Pedagogical practices (X3) included lesson planning, strategy variation, discussion management, student-centred activity, and reflection. Learning quality in deep learning implementation (Y) referred to meaningful, mindful, and joyful learning as well as deeper understanding and higher-order thinking. The instruments were piloted with 30 teachers outside the main sample. After instrument testing, the final scales contained 30 items for Y, 30 items for X1, 18 items for X2, and 18 items for X3.

Data were analyzed using IBM SPSS. Descriptive statistics summarized each variable, and

Pearson correlations examined relationships among constructs. Simple regression was used to describe the bivariate relationship of each independent variable with learning quality, while multiple linear regression examined the three predictors simultaneously. Before regression, residual normality, linearity, multicollinearity, and heteroscedasticity were assessed. The Glejser test indicated heteroscedasticity for digital technology use and pedagogical practices. Therefore, rather than transforming the original composite scores, the final multiple-regression inference used heteroscedasticity-consistent HC3 robust standard errors for coefficient standard errors, t statistics, confidence intervals, and partial p values. OLS coefficients and model-fit statistics were retained, while joint significance was evaluated with an HC3 robust Wald F test. Statistical decisions used a 5% significance level. Because the survey was cross-sectional, the results are interpreted as statistical relationships rather than definitive causal effects.

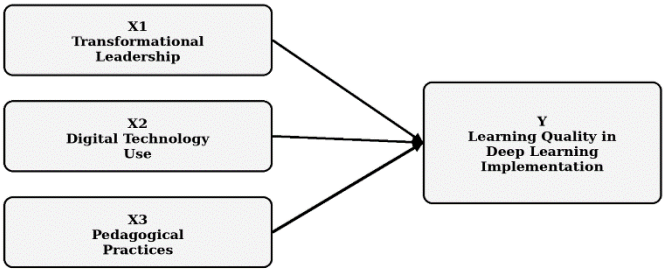


Figure 1. Research Framework.

Figure 1 presents three conceptually complementary variables. Transformational leadership represents school-level organizational support, digital technology use represents the purposeful use of digital resources and tools, and pedagogical practices represent classroom implementation. Their relationships with learning quality in deep learning implementation were examined both separately and simultaneously.

FINDINGS AND DISCUSSION

Findings

The findings are presented from data description and bivariate relationships to regression assumptions and regression results. All analyses used 137 complete responses.

Table 1. Descriptive Statistics of Study Variables

Variable	N	Minimum	Maximum	Mean	SD
Transformational Leadership (X1)	137	102	150	127.584	13.157

Digital Technology Use (X2)	137	49	90	72.467	7.179
Pedagogical Practices (X3)	137	52	90	73.569	7.487
Learning Quality (Y)	137	79	150	122.044	11.840

Source: Primary data processed with SPSS, 2026.

Table 1 shows sufficient variation across the four study variables. Mean scores were 127.584 for transformational leadership, 72.467 for digital technology use, 73.569 for pedagogical practices, and 122.044 for learning quality. The standard deviations indicate meaningful variation among teachers rather than responses clustering at a single score, providing a reasonable basis for subsequent correlation and regression analyses.

Table 2. Pearson Correlations among Study Variables

Variable	X1	X2	X3	Y
X1 Transformational Leadership	1	.555***	.532***	.509***
X2 Digital Technology Use	.555***	1	.758***	.547***
X3 Pedagogical Practices	.532***	.758***	1	.538***
Y Learning Quality	.509***	.547***	.538***	1

Source: Primary data processed with SPSS, 2026. Note: *** $p < .001$; N = 137.

Table 2 shows positive relationships between all three independent variables and learning quality. The strongest bivariate relationship was between digital technology use and learning quality ($r = .547$), followed by pedagogical practices ($r = .538$) and transformational leadership ($r = .509$); all were significant at $p < .001$. Digital technology use and pedagogical practices were also strongly correlated ($r = .758$), but the subsequent VIF values remained below levels indicating problematic multicollinearity.

Regression diagnostics showed that the residuals met the normality assumption, with a Kolmogorov–Smirnov statistic of .076 and $p = .052$. The relationships of X1, X2, and X3 with Y also met the linearity assumption because deviation-from-linearity tests yielded $p = .626$, $p = .576$, and $p = .082$, respectively. Tolerance values ranged from .393 to .663 and VIF values from 1.509 to 2.547, indicating no multicollinearity problem that would prevent multiple regression analysis.

The Glejser test indicated no heteroscedasticity for transformational leadership ($p = .520$), but it detected heteroscedasticity for digital technology use ($p = .036$) and pedagogical practices ($p = .016$). To obtain heteroscedasticity-consistent partial inference without changing the scale of the variables, the multiple-regression model was therefore evaluated using HC3 robust standard errors.

This correction leaves the estimated regression coefficients and R^2 unchanged but adjusts the standard errors, t statistics, confidence intervals, and p values reported for the final model.

In the simple regressions, each independent variable was significantly related to learning quality. Transformational leadership produced R = .509 and R^2 = .259, digital technology use R = .547 and R^2 = .299, and pedagogical practices R = .538 and R^2 = .289; all models had $p < .001$. Thus, when examined separately, each variable showed a meaningful relationship with learning quality.

Table 3. Multiple Linear Regression of Learning Quality

Variable	B	SE	β	t	p
Constant	38.343	9.314	—	4.117	< .001
Transformational Leadership (X1)	.235	.075	.261	3.113	.002
Digital Technology Use (X2)	.385	.180	.234	2.144	.034
Pedagogical Practices (X3)	.351	.169	.222	2.072	.040

Source: Primary data processed with SPSS, 2026.

Table 3 shows that all regression coefficients remained positive when the three predictors were entered into the same model. Using HC3 robust inference, transformational leadership remained statistically significant (B = .235, robust SE = .096, p = .016), whereas digital technology use (B = .385, robust SE = .222, p = .085) and pedagogical practices (B = .351, robust SE = .217, p = .108) did not reach the .05 significance level after correction. The standardized beta coefficients remained $\beta = .261$, $\beta = .234$, and $\beta = .222$, respectively; however, beta magnitude should not be interpreted as statistical significance. The model retained R = .616 and adjusted R^2 = .366, while the HC3 robust joint test was significant, $F(3, 133) = 19.058$, $p < .001$. Thus, the predictors were jointly related to learning quality, with the clearest independent evidence found for transformational leadership.

Discussion

Transformational leadership remained positively and significantly related to learning quality even after accounting for digital technology use and pedagogical practices, and after applying the HC3 robust correction (B = .235, p = .016). This result is plausible because instructional change requires direction, support, and room for teachers to experiment with new practices. Shen and Wu (2025) show that principal leadership is related to student outcomes through multiple pathways rather than only through principals' direct classroom actions. He et al. (2024) likewise emphasize that learning-focused leadership can strengthen teacher professional development. Huang et al. (2024) identify teacher professional learning as an important link between leadership

and instructional quality. In the present study, the robust result suggests that principals' vision, motivation, intellectual stimulation, and individualized support provide a distinct contribution to the conditions that support deep learning.

Digital technology use had a positive bivariate correlation with learning quality ($r = .547$, $p < .001$), but its partial coefficient did not reach the .05 level after HC3 robust correction ($B = .385$, $p = .085$). This means that the study provides clear evidence of an association at the bivariate level, but not sufficient evidence that technology use explains unique variance after leadership and pedagogical practices are considered simultaneously. Yang et al. (2023) show that teacher digital competence includes knowledge, skills, and the capacity to apply technology in instructional situations. Schmid et al. (2024) emphasize that TPACK is contextual and develops through practice, while Petko et al. (2025) place school context at the center of how technological-pedagogical knowledge is enacted. The strong correlation between technology use and pedagogical practices in this study ($r = .758$) may also indicate shared variance between the two constructs. Technology should therefore be interpreted as a complementary instructional resource rather than as an independently confirmed predictor in the final robust model.

Pedagogical practices also showed a positive bivariate correlation with learning quality ($r = .538$, $p < .001$), yet the partial coefficient was not statistically significant after HC3 robust correction ($B = .351$, $p = .108$). This finding does not imply that pedagogy is unimportant; rather, it indicates that its unique statistical contribution could not be distinguished clearly from the other predictors in this sample. Cai et al. (2023) show that feedback in technology-rich environments is effective when students receive information they can use to improve understanding and performance. Brummer et al. (2024) emphasize that digital feedback depends on context, content, and task characteristics. Prasse et al. (2024) similarly show that technology does not automatically produce self-regulation. Wijnia et al. (2024) report motivational benefits of problem- and project-based approaches. Zhang et al. (2024) likewise report gains in computational thinking under project-based learning. These studies support the continuing pedagogical importance of discussion, problem solving, reflection, and student-centred activity, even though the present robust model did not establish an independent partial effect at the .05 level.

Within the Indonesian deep-learning context, the findings also fit the emerging character of the approach. Feri (2025) argues that meaningful, mindful, and joyful learning requires teachers to redesign learning rather than simply deliver content. Nurrani and Herlambang (2025) view deep

learning as a space for strengthening student participation and awareness. Siregar et al. (2025) show the importance of connecting concepts with authentic contexts and reflective learning experiences. Leadership, technology, and pedagogy should therefore not be treated as three separate programs. They operate at different levels but converge on the same aim: making learning more meaningful and giving students opportunities to understand, apply, and reflect on knowledge.

The standardized beta coefficients were relatively close (β = .261, .234, and .222), but the HC3 robust tests show that coefficient magnitude and statistical certainty should be distinguished. Only transformational leadership remained significant as an individual predictor, whereas the technology and pedagogy coefficients remained positive but more uncertain. At the same time, the HC3 robust joint test confirmed that the three-predictor model was significant. This pattern supports an integrated school-improvement view at the model level while cautioning against claiming that each predictor has an independently significant effect. Hase and Kuhl (2024) show that digital data become useful only when teachers turn them into instructional decisions. Roudhoh et al. (2026) demonstrate the importance of teacher digital competence for effective digital-media use. Qomariyah et al. (2026) show that integrated project-based learning can improve student activity and outcomes.

An adjusted R^2 of 36.59% indicates that the model offers a meaningful explanation but does not account for all variation in learning quality. Approximately 63.41% of the variation remains outside the three variables examined. This proportion cannot be assigned directly to any specific factor, but it indicates that learning quality is shaped by multiple interacting conditions. Claro et al. (2024) show that teacher digital competence itself has several dimensions and is not measured uniformly across studies. Ma and Ismail (2025) likewise document the diversity of digital-competence research across contexts and educational levels. On the pedagogical side, Zhang and Ma (2023) show that project-based learning outcomes vary with implementation characteristics. Future studies could therefore examine school learning culture, teacher efficacy, parental support, student characteristics, and the quality of deep-learning implementation.

The practical implication is that school-quality initiatives should be coordinated rather than fragmented. Leadership development can focus on principals' ability to guide instructional change and strengthen teacher collaboration. Digital professional development should move beyond application training toward media selection, digital-resource management, data use, and instructional design. At the same time, pedagogical development should emphasize contextual

tasks, meaningful discussion, problem solving, projects, reflection, and feedback. Susanti et al. (2025) show that digital media can support science learning when aligned with learning purposes. Setyowati and Utami (2025) demonstrate the value of deliberately designed learning scenarios for higher-order thinking. The goal is not to add as much technology or as many methods as possible, but to ensure that each choice strengthens students' learning experiences.

This study has several limitations. Data were collected through teacher questionnaires within one district and at one period in time, so the findings describe relationships in this context and should not be generalized automatically to all elementary schools. The Glejser test identified heteroscedasticity for X2 and X3; as a corrective measure, the final multiple-regression inference used HC3 robust standard errors rather than data transformation. HC3 reduces bias in standard-error estimation under heteroscedasticity but does not remove the limitations of cross-sectional self-report data or establish causality. Future studies should use broader samples, multiple data sources, longitudinal or multilevel designs, and, where appropriate, additional robust or resampling procedures to test the stability of the relationships found here.

CONCLUSION

This study shows that transformational leadership, digital technology use, and pedagogical practices are each positively correlated with learning quality in deep learning implementation in elementary schools in Bulakamba District. The three-predictor model was also jointly significant under HC3 robust inference and explained approximately 36.59% of the variation in learning quality. However, after heteroscedasticity was addressed with HC3 robust standard errors, only transformational leadership remained statistically significant as an individual predictor ($p = .016$); digital technology use ($p = .085$) and pedagogical practices ($p = .108$) retained positive coefficients but did not reach the .05 level. The results therefore provide the strongest independent evidence for leadership while supporting technology and pedagogy as complementary components of the broader school-learning environment.

For schools, the findings suggest that improvement efforts should remain coordinated but evidence-sensitive. Principals should strengthen instructional direction, professional learning, and support for innovation. Digital development should focus on purposeful integration rather than device use alone, and pedagogical development should continue to emphasize meaningful, reflective, and student-centred learning. Future research should test the model across broader

settings and with designs that can separate the unique and shared contributions of leadership, technology, and pedagogy more precisely.

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