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The Effect of Transformational Leadership and Digital Literacy on Students' Academic Achievement through Learning Innovation in State Senior High Schools Across Cilegon City

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ABSTRACT

This study aims to examine the influence of transformational leadership and digital literacy on student academic achievement, both directly and through learning innovation as an intervening variable, in Public Senior High Schools in Cilegon City. Research Methodology. This study uses a quantitative approach with an explanatory research type. Data were collected through a Likert-scale questionnaire distributed to 155 teachers selected using proportional stratified random sampling techniques from a population of 259 teachers in five Public Senior High Schools in Cilegon City. Academic achievement data were taken from the documentation of grade XI student report card grades in the odd semester of the 2025/2026 academic year. Data analysis was carried out using the Structural Equation Modeling approach based on Partial Least Squares (SEM-PLS) using the SmartPLS 3 application, including evaluation of the measurement model, structural model, and bootstrapping test. Results. The results showed that transformational leadership and digital literacy had a positive and significant effect on learning innovation and on academic achievement. Learning innovation was also proven to have a positive and significant effect on academic achievement and was able to mediate the influence of both independent variables on academic achievement. The R Square value shows that learning innovation is explained by 77.1 percent by transformational leadership and digital literacy, while academic achievement is explained by 62.1 percent by the three variables studied. Conclusion. The transformational leadership of the principal and the digital literacy skills of teachers are important factors that encourage the realization of learning innovation, which in turn helps improve student academic achievement in public senior high schools in Cilegon City. Limitations. This study was only conducted in five public senior high schools in one city area so that the findings cannot necessarily be generalized to other contexts, and the measurement of variables is perceptional through questionnaires so that it still has the potential to contain respondent subjectivity bias. Contribution. This study enriches the study of educational management regarding the role of learning innovation as a connecting mechanism between school leadership and digital literacy with student learning outcomes, and provides practical input for principals, teachers, and the education office in formulating policies to improve the quality of learning at the senior high school level.

Article Information

Keywords:
kepemimpinan transformasional, literasi digital, inovasi pembelajaran, prestasi akademik siswa

ABSTRACT

Penelitian ini bertujuan untuk menguji pengaruh kepemimpinan transformasional dan literasi digital terhadap prestasi akademik siswa, baik secara langsung maupun melalui inovasi pembelajaran sebagai variabel intervening, pada Sekolah Menengah Atas Negeri se-Kota Cilegon. Metodologi Penelitian. Penelitian ini menggunakan pendekatan kuantitatif dengan jenis penelitian eksplanatori. Data dikumpulkan melalui kuesioner berskala Likert yang dibagikan kepada 155 guru yang dipilih dengan teknik proportional stratified random sampling dari populasi 259 guru pada lima SMA Negeri di Kota Cilegon. Data prestasi akademik diambil dari dokumentasi nilai rapor siswa kelas XI semester ganjil tahun ajaran 2025/2026. Analisis data dilakukan dengan pendekatan Structural Equation Modeling berbasis Partial Least Squares (SEM-PLS) menggunakan aplikasi SmartPLS 3, mencakup evaluasi model pengukuran, model struktural, dan uji bootstrapping. Hasil. Hasil penelitian menunjukkan bahwa kepemimpinan transformasional dan literasi digital berpengaruh positif dan signifikan terhadap inovasi pembelajaran serta terhadap prestasi akademik. Inovasi pembelajaran juga terbukti berpengaruh positif dan signifikan terhadap prestasi akademik dan mampu memediasi pengaruh kedua variabel independen terhadap prestasi akademik. Nilai R Square menunjukkan bahwa inovasi pembelajaran dijelaskan sebesar 77,1 persen oleh kepemimpinan transformasional dan literasi digital, sedangkan prestasi akademik dijelaskan sebesar 62,1 persen oleh ketiga variabel yang diteliti. Kesimpulan. Kepemimpinan transformasional kepala sekolah dan kemampuan literasi digital guru merupakan faktor penting yang mendorong terwujudnya inovasi pembelajaran, yang pada gilirannya turut meningkatkan prestasi akademik siswa di SMA Negeri se-Kota Cilegon. Keterbatasan. Penelitian ini hanya dilaksanakan pada lima SMA Negeri di satu wilayah kota sehingga temuannya belum tentu dapat digeneralisasikan pada konteks lain, dan pengukuran variabel bersifat persepsional melalui kuesioner sehingga tetap berpotensi mengandung bias subjektivitas responden. Kontribusi. Penelitian ini memperkaya kajian manajemen pendidikan mengenai peran inovasi pembelajaran sebagai mekanisme penghubung antara kepemimpinan sekolah dan literasi digital dengan capaian belajar siswa, serta memberikan masukan praktis bagi kepala sekolah, guru, dan dinas pendidikan dalam merumuskan kebijakan peningkatan mutu pembelajaran di jenjang sekolah menengah atas.

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1. INTRODUCTION

Student academic achievement is an important indicator of the extent to which learning activities support the attainment of curricular objectives. At the senior high school level, academic achievement is commonly reflected in assessment results and report card grades. However, student achievement is shaped by multiple factors, including the quality of school leadership, teachers' professional competencies, and the learning practices implemented in classrooms. From an educational management perspective, understanding how these factors work together is important for developing strategies to support learning quality.

A preliminary review of daily test score records conducted by the researchers involving 100 Grade XI students from five public senior high schools in Cilegon City indicated that the average score was 79.6, while approximately 48% of the students had not achieved the Learning Objective Completion Criteria (KKTP) established by their respective schools. The preliminary findings also indicated variations in achievement across the schools. These figures provide an initial indication of learning challenges in the research context; however, they should not be interpreted as representative estimates of all Grade XI students in Cilegon City because the preliminary review involved a limited group of students. The interpretation of these data also depends on the assessment period, the distribution of students across the five schools, and the criteria used by each school. Therefore, the final manuscript should specify the actual period of document collection and the number of students reviewed at each school to make the preliminary evidence transparent.

One factor that may be associated with the quality of classroom learning is the principal's transformational leadership. Transformational leadership emphasizes the development of a shared vision, inspirational motivation, intellectual stimulation, and individualized consideration. In schools, these practices may help establish a supportive environment in which teachers are encouraged to develop their professional capabilities and explore alternative approaches to teaching. Mincu (2022) highlights the importance of school leadership in educational transformation, while Ali and Haider (2023) discuss the role of transformational educational leadership in fostering educators' commitment. Andriani, Kesumawati, and Kristiawan (2024) also examine transformational leadership in relation to teacher work performance. Together, these studies provide a basis for expecting that transformational leadership may be associated with learning innovation and student academic achievement. Nevertheless, leadership does not necessarily translate directly into changes in classroom practice; its contribution may depend on whether teachers can turn leadership support into practical instructional activities.

Teachers' digital literacy is another relevant factor in contemporary education. In this study, digital literacy refers specifically to teachers' perceived ability to access, understand, evaluate, and use digital technology safely, critically, and responsibly in educational activities. It does not refer to students' digital literacy. This distinction is important because the study measures teachers' digital literacy through questionnaire responses, whereas student academic achievement is obtained from Grade XI report card documentation for the odd semester of the 2025/2026 academic year. The proposed relationship between these variables therefore concerns how teachers' digital competencies may be associated with the learning opportunities and instructional practices they provide, rather than a direct measurement of students' own digital competencies.

Previous research has connected teachers' digital competence with educational technology use and innovation. Timotheou et al. (2022), in their review of digital technologies in education, identify school digital capacity as an important consideration in educational transformation. López-Gómez, Sáez-López, and Miranda-Perea (2021) examine the relationship between teacher digital competence and school innovation, while Landa, Sunaryo, and Tampubolon (2021) investigate teachers' digital literacy in relation to learning management and students' learning interests. These studies support the relevance of teacher digital literacy to instructional processes. However, digital literacy alone does not ensure that technology will be integrated meaningfully into teaching. Teachers must also select appropriate resources, learning methods, and assessment practices in accordance with instructional objectives and students' learning needs.

Learning innovation may provide a mechanism through which transformational leadership and teachers' digital literacy are associated with academic achievement. In this study, learning innovation refers to teachers' development and implementation of instructional practices intended to make learning more active, varied, and responsive to learning objectives. Such practices may include the use of different learning models, teaching methods, digital or interactive media, and assessment activities. Transformational leadership may provide encouragement and organizational support for teachers to experiment with instructional approaches, while digital literacy may provide the competencies needed to select and use digital resources in those approaches. When these conditions are translated into appropriate classroom practices, students may have greater opportunities to engage with learning materials and demonstrate their understanding. This proposed mechanism is theoretically plausible, although its strength must be examined empirically rather than assumed.

Several previous studies have examined relationships between school leadership, digital literacy, innovation, and learning outcomes. Amarta, Zakiya, and Gistituati (2023) discuss transformational leadership in relation to teacher motivation, while Sari et al. (2023) examine principal leadership and teacher professionalism in relation to effective schools. Studies of digital literacy have also investigated its relationship with learning interests and academic achievement, including Landa et al. (2021) and Khasanah and Yushita (2023). In addition, López-Gómez et al. (2021) examine teacher digital competence and school innovation, and Suryadi, Muslim, and Setyono (2024) explore digital leadership and digital literacy in relation to higher education performance through digital innovation.

Although these studies provide relevant insights, they address different relationships, populations, and educational settings. Findings concerning students' own digital literacy, for example, cannot automatically be treated as evidence about teachers' digital literacy. Similarly, evidence from higher education or other school levels may not directly explain the relationships among the variables in public senior high schools. The specific research problem addressed in this study is therefore not simply the limited use of an integrated model. Rather, it is the need to examine whether learning innovation statistically mediates the relationships of transformational leadership and teachers' digital literacy with student academic achievement within the context of public senior high schools in Cilegon City. The model distinguishes the direct relationships between the two predictor variables and academic achievement from their indirect relationships through learning innovation.

This study addresses that problem by examining transformational leadership and teachers' digital literacy as independent variables, learning innovation as an intervening variable, and student academic achievement as the outcome variable. The analysis uses questionnaire responses from 155 teachers across five public senior high schools in Cilegon City and Grade XI report card documentation for the odd semester of the 2025/2026 academic year. Because the predictor and intervening constructs are measured through teacher perceptions while academic achievement is derived from report card records associated with the respondent teachers' classes, the findings should be interpreted as evidence of statistical relationships between teacher-reported constructs and the documented achievement measure. They should not be interpreted as proof that individual students' digital literacy or perceptions were measured directly.

The study's contribution lies in testing a specific mediation model in a local public senior high school context. By examining both direct paths and indirect paths through learning innovation, the study provides evidence on whether instructional innovation may function as a statistical link between transformational leadership, teachers' digital literacy, and academic achievement. This contribution is more specific than merely combining variables in one model: it examines the proposed intermediary role of classroom learning practices while distinguishing teacher-level perceptions from documented student achievement. The findings may inform principals and education policymakers when considering how leadership practices and teacher digital development can be connected with instructional innovation. Nevertheless, the extent to which the findings apply beyond the five schools must be considered in light of the study's context and measurement design.

Based on the theoretical arguments and previous research discussed above, the study formulates the following hypotheses:

H1: Transformational leadership is positively associated with learning innovation.

H2: Teachers' digital literacy is positively associated with learning innovation.

H3: Transformational leadership is positively associated with student academic achievement.

H4: Teachers' digital literacy is positively associated with student academic achievement.

H5: Learning innovation is positively associated with student academic achievement.

H6: Learning innovation mediates the relationship between transformational leadership and student academic achievement.

H7: Learning innovation mediates the relationship between teachers' digital literacy and student academic achievement.

2. RESEARCH METHODS

2.1 Research Design and Setting

This study employed a quantitative explanatory design to examine the relationships among transformational leadership, teachers' digital literacy, learning innovation, and student academic achievement. The research was conducted in five public senior high schools in Cilegon City, Banten Province, Indonesia: SMA Negeri 1 Cilegon, SMA Negeri 2 Krakatau Steel Cilegon, SMA Negeri 3 Cilegon, SMA Negeri 4 Cilegon, and SMA Negeri 5 Cilegon. Data collection was conducted in mid-to-late June 2026, while data processing and analysis took place from June to July 2026. As the study used observational data collected within a single period, the results were interpreted as statistical relationships within the proposed model rather than definitive evidence of causal effects.

2.2 Population and Sampling

The population consisted of 259 teachers who were actively teaching in the five public senior high schools during the 2025/2026 academic year. A total of 155 teachers were selected using proportional stratified random sampling, with each school serving as a stratum. The sample comprised 37 teachers from SMA Negeri 1 Cilegon, 39 from SMA Negeri 2 Krakatau Steel Cilegon, 31 from SMA Negeri 3 Cilegon, 23 from SMA Negeri 4 Cilegon, and 25 from SMA Negeri 5 Cilegon.

The initial sample-size determination used an indicator-based heuristic. The research model comprised 31 indicators: eight for transformational leadership, sixteen for teachers' digital literacy, six for learning innovation, and one for academic achievement. Applying the five-times-indicator rule yielded a sample of 155 respondents. However, this rule provides an initial estimate and does not independently establish adequate statistical power for detecting all structural relationships, particularly indirect effects. Therefore, the sample-size rationale should be interpreted with this limitation in mind. The sample of 155 teachers was subsequently used for the PLS-SEM analysis.

2.3 Unit of Analysis and Measurement of Academic Achievement

Teachers served as the primary unit of analysis because transformational leadership, teachers' digital literacy, and learning innovation were measured through questionnaire responses provided by teachers. Academic achievement was measured using documented Grade XI student report-card grades for the odd semester of the 2025/2026 academic year, specifically in the subjects taught by the participating teachers.

The use of teacher-level questionnaire data and student report-card records required the achievement data to be associated with the relevant teaching assignments. Accordingly, the interpretation of the results depends on the procedure used to link each teacher with the corresponding student grades and to calculate the achievement score. The resulting achievement measure represents the academic performance associated with the participating teachers' teaching assignments rather than a direct measure of each teacher's individual characteristics. Because the study included data originating at different levels, the findings should be interpreted cautiously and should not automatically be generalized to individual students without considering the data-linkage procedure.

2.4 Research Instruments and Operational Definitions

Primary data were collected using a questionnaire with a five-point Likert scale to measure transformational leadership, teachers' digital literacy, and learning innovation from teachers' perspectives. Academic achievement was measured separately using report-card documentation rather than questionnaire responses.

Transformational leadership was measured using eight indicators representing four dimensions: idealized influence, inspirational motivation, intellectual stimulation, and individualized consideration. These indicators reflected teachers' perceptions of the transformational leadership practices demonstrated by their school principals.

Teachers' digital literacy was measured using sixteen indicators covering the abilities to access, understand, evaluate, and use digital technology safely and responsibly. This construct referred specifically to teachers' digital literacy rather than students' digital literacy. The proposed relationship with academic achievement was examined in terms of the potential connection between teachers' digital competencies and their classroom practices.

Learning innovation was measured using six indicators representing innovative teaching and learning practices. This construct was positioned as a mediating variable to examine whether learning innovation statistically accounted for part of the relationships between transformational leadership, teachers' digital literacy, and student academic achievement.

The operationalization of these constructs was based on their respective conceptual definitions. The sources of the measurement scales, questionnaire-item development, and any adaptation procedures should be reported transparently to enable replication and to establish the correspondence between the theoretical constructs and their indicators.

2.5 Data Collection

Questionnaires were used as the primary data-collection technique for transformational leadership, teachers' digital literacy, and learning innovation. Academic-achievement data were obtained through documentation of Grade XI student report-card grades for the odd semester of the 2025/2026 academic year. These records provided the academic-achievement measure used in the statistical model.

The analysis reported in this study focused on questionnaire data and report-card documentation. Accordingly, the interpretation of the findings was based on these quantitative data sources. Any additional techniques, such as interviews or classroom observations, were not treated as evidence in the reported statistical analysis unless their procedures and analytical contributions were explicitly documented.

2.6 Data Analysis

Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 3. The analysis involved evaluating the measurement model and the structural model. The measurement model was assessed using indicator loadings, internal-consistency measures, and convergent and discriminant validity criteria, as appropriate to the measurement specification of each construct.

The structural model was evaluated using path coefficients and the coefficient of determination (R^2). Bootstrapping was used to assess the statistical significance of the hypothesized direct and indirect relationships. The mediation hypotheses were examined through the specific indirect effects of transformational leadership and teachers' digital literacy on academic achievement through learning innovation. Statistical significance was assessed using the bootstrapping results, with a significance threshold of 0.05.

Academic achievement was operationalized as a single-indicator construct based on report-card grades. Therefore, its Cronbach's Alpha, rho_A, Composite Reliability, and Average Variance Extracted (AVE) values of 1.000 were not interpreted in the same manner as the corresponding values for multi-indicator constructs. For a single-indicator construct, these values may result from the measurement specification and do not independently demonstrate perfect reliability. The measurement properties of academic achievement were consequently interpreted in accordance with its single-indicator operationalization, while reliability and validity assessments for the multi-item constructs were considered separately.

2.7 Methodological Limitations

The study involved teachers from five schools, and respondents within the same school shared a principal, institutional policies, and organizational environments. These shared conditions may have produced similarities among

responses from teachers within the same school. Although proportional stratified random sampling ensured that teachers from each school were represented, this sampling procedure did not by itself account statistically for possible within-school dependence.

The reported PLS-SEM analysis did not explicitly establish an adjustment for school-level clustering. Consequently, possible dependence among teachers from the same school should be considered when interpreting the estimated standard errors and significance tests. Furthermore, the study was limited to five public senior high schools in one city and used observational data collected within a single period. The findings therefore indicate statistical relationships within the specified sample and model; they do not independently establish causal relationships or guarantee generalizability to other educational settings.

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics

This study involved 155 teachers from five public senior high schools in Cilegon City. Data on transformational leadership, teachers' digital literacy, and learning innovation were collected through questionnaires, while academic achievement was measured using Grade XI student report-card records for the odd semester of the 2025/2026 academic year.

The descriptive results showed that transformational leadership had a mean score of 31.30, with a possible score range of 24–40. Teachers' digital literacy had a mean score of 63.26, with a possible score range of 48–80. Learning innovation had a mean score of 23.50, with a possible score range of 18–30. Academic achievement had a mean score of 83.19, with observed scores ranging from 80 to 92.

These descriptive statistics provide an overview of the measured variables. However, categorical labels such as "good" or "high" are not used here because explicit cut-off points for classifying the mean scores were not specified in the original analysis. The interpretation therefore focuses on the reported means and score ranges rather than on categories that cannot be independently verified.

3.2 Measurement Model Evaluation

The measurement model was evaluated using indicator loadings, internal-consistency reliability, convergent validity, and discriminant validity. The original analysis reported that all multi-item indicators had outer loadings above 0.70. However, the individual loading values were not presented in the original results table. Therefore, the statement regarding indicator loadings should be supported by a complete table containing the loading value of each indicator.

Table 1. Results of Reliability and Construct Validity Tests

Variables	Cronbach's Alpha	rho_A	Composite Reliability	AVE
Transformational Leadership (X1)	0.936	0.938	0.950	0.763
Digital Literacy (X2)	0.963	0.965	0.967	0.696
Learning Innovation (Y)	0.955	0.957	0.964	0.817
Academic Achievement (Z)	1,000	1,000	1,000	1,000

Source: SmartPLS 3 output, processed data (2026)

The results indicate that the three multi-item constructs exceeded the commonly applied thresholds of 0.70 for internal-consistency reliability and 0.50 for AVE. These results support the reliability and convergent validity of the multi-item measures.

Academic achievement, however, was measured using a single indicator based on report-card grades. Its reliability and AVE values of 1.000 should not be interpreted as evidence of perfect measurement reliability. For a single-indicator construct, these values may arise from the model specification and do not provide the same information as reliability and validity statistics for multi-item constructs.

Discriminant validity should also be reported using the relevant results from SmartPLS, such as the heterotrait-monotrait ratio (HTMT) or the Fornell–Larcker criterion. Because the corresponding numerical results were not provided in the original results table, the conclusion that all constructs satisfy discriminant validity cannot be independently verified from the information reported here.

3.3 Model Fit Evaluation

The model fit assessment produced an SRMR value of 0.061, an NFI value of 0.768, and an RMS Theta value of 0.174. These indices provide different information about the model and should be interpreted separately.

The SRMR value of 0.061 is below the commonly applied threshold of 0.080, indicating an acceptable level of discrepancy between the observed and model-implied correlations according to this criterion. In contrast, the NFI value of 0.768 indicates that the model does not achieve a high level of fit according to more stringent NFI benchmarks commonly used in structural equation modeling. The RMS Theta value of 0.174 is also above the 0.12 reference value cited in the original manuscript, suggesting that the residual

correlations associated with the reflective measurement model warrant further consideration.

The original analysis also reported d_ULS of 1.290 and d_G of 1.725. These values should not be interpreted independently as evidence of good fit without comparison with the appropriate bootstrap-based reference values. Taken together, the fit indices present a mixed assessment: SRMR meets the stated criterion, whereas NFI and RMS Theta indicate areas of concern. Accordingly, the model fit should not be described as uniformly good solely because the SRMR value meets its threshold. The structural results should be interpreted alongside these model-fit considerations.

3.4 Structural Model and Direct Hypothesis Testing

The structural model was assessed using path coefficients, t-statistics, and p-values obtained through bootstrapping in SmartPLS 3. The significance threshold was set at 0.05. Table 2 presents the results of the direct hypothesis tests.

Table 2. Path Coefficient Test Results

Hypothesis	Path of Influence	Path Coefficient	t-statistic	p-values	Decision
H1	Transformational Leadership -> Learning Innovation	0.279	3.07	0.002	Accepted
H2	Digital Literacy -> Learning Innovation	0.629	7,554	0,000	Accepted
H3	Transformational Leadership -> Academic Achievement	0.159	2,388	0.017	Accepted
H4	Digital Literacy -> Academic Achievement	0.396	4,183	0,000	Accepted
H5	Learning Innovation -> Academic Achievement	0.273	3,316	0.001	Accepted
H6	Transformational Leadership -> Learning Innovation -> Academic Achievement	0.076	2,219	0.027	Accepted
H7	Digital Literacy -> Learning Innovation -> Academic Achievement	0.172	3,056	0.002	Accepted

Source: SmartPLS 3 output, processed data (2026)

The results show a positive and statistically significant relationship between transformational leadership and learning innovation ($\beta = 0.279$, $t = 3.072$, $p = 0.002$). This finding supports H1 and suggests that more favorable perceptions of transformational leadership were associated with higher reported levels of learning innovation.

Teachers' digital literacy was also positively associated with learning innovation ($\beta = 0.629$, $t = 7.554$, $p < 0.001$), supporting H2. Within the estimated model, its standardized path coefficient was numerically larger than that of transformational leadership. This comparison indicates a stronger estimated association with learning innovation in this particular sample and model. It does not establish that digital literacy is universally more important than leadership across other schools or educational contexts, nor does it establish that the difference between the two coefficients is statistically significant.

Transformational leadership was positively associated with academic achievement ($\beta = 0.159$, $t = 2.388$, $p = 0.017$), supporting H3. Teachers' digital literacy also showed a positive and statistically significant relationship with academic achievement ($\beta = 0.396$, $t = 4.183$, $p < 0.001$), supporting H4. In addition, learning innovation was positively associated with academic achievement ($\beta = 0.273$, $t = 3.316$, $p = 0.001$), supporting H5.

These findings indicate that all five hypothesized direct relationships were statistically significant at the 0.05 level. Because the study used an observational design, the path coefficients represent associations estimated within the specified model and should not be interpreted as conclusive evidence that changes in one variable necessarily cause changes in another.

Table 3. Results of Specific Indirect Effects Tests

3.5 Mediation Analysis

The mediating role of learning innovation was examined through the specific indirect effects estimated using bootstrapping. Table 3 presents the reported indirect-effect coefficients, t-statistics, and p-values.

R Square Value

Table 4. R Square Value

Endogenous Variables	R Square	Category
Learning Innovation (Y)	0.771	Strong
Academic Achievement (Z)	0.621	Currently

Source: SmartPLS 3 output, processed data (2026)

The indirect relationship between transformational leadership and academic achievement through learning innovation was positive and statistically significant ($\beta = 0.076$, $t = 2.219$, $p = 0.027$). This result supports H6 and indicates that learning innovation statistically mediates the relationship between transformational leadership and academic achievement in the estimated model.

Similarly, the indirect relationship between teachers' digital literacy and academic achievement through learning innovation was positive and statistically significant ($\beta = 0.172$, $t = 3.056$, $p = 0.002$). This result supports H7, indicating that learning innovation also serves as a statistical mediator in the relationship between teachers' digital literacy and academic achievement.

The direct relationships from transformational leadership and digital literacy to academic achievement were also statistically significant. This pattern is consistent with complementary partial mediation, given that the reported direct and indirect coefficients are positive and statistically significant. Nevertheless, the mediation results should be interpreted with appropriate caution. Bootstrap confidence intervals for the indirect effects were not reported in the available results and should be included in the final statistical reporting to provide additional information about the precision of the estimates. The significant indirect effects do not, by themselves, establish a causal mechanism.

4. Discussion

The findings indicate that transformational leadership and teachers' digital literacy were positively associated with learning innovation and academic achievement, while learning innovation was positively associated with academic achievement and statistically mediated the relationships between the two explanatory variables and academic achievement. However, the strength and interpretation of these relationships differ across the proposed pathways. These differences provide a basis for examining how leadership, teachers' digital competencies, and instructional practices may relate to academic outcomes in the five public senior high schools in Cilegon City.

4.1 Transformational Leadership and Learning Innovation

The positive relationship between transformational leadership and learning innovation ($\beta = 0.279$, $p = 0.002$) suggests that teachers who perceive their principals as demonstrating stronger transformational leadership also tend to report greater learning innovation. One possible explanation is that principals who encourage professional development, communicate a shared vision, provide intellectual stimulation, and recognize teachers' individual needs may create organizational conditions that support experimentation with teaching practices. In this context, leadership may be associated with innovation by shaping teachers' perceived opportunities and willingness to explore alternative instructional approaches.

This interpretation is consistent with the discussion of leadership and innovative work behavior in Andriani, Kesumawati, and Kristiawan (2024) and Messmann, Evers, and Kreijns (2022). However, the present findings do not directly demonstrate that psychological support, professional autonomy, or access to resources mediated the relationship, because these factors were not separately measured in the proposed model. They should therefore be understood as plausible explanations rather than established mechanisms.

The coefficient for transformational leadership was smaller than that for teachers' digital literacy in predicting learning innovation. This difference may indicate that leadership is associated with innovation through broader organizational conditions, whereas digital literacy may be more directly connected to the practical tasks involved in designing and implementing innovative lessons. Nevertheless, leadership may remain important because teachers' ability to innovate can depend not only on their individual competencies but also on the opportunities, resources, and institutional support available to them. The relative coefficients should therefore be interpreted within this particular model and sample rather than as evidence that leadership is generally less important than digital literacy.

4.2 Teachers' Digital Literacy and Learning Innovation

Teachers' digital literacy had a positive relationship with learning innovation ($\beta = 0.629$, $p < 0.001$). Among the direct paths to learning innovation, this was the largest estimated coefficient in the model. The finding suggests that teachers who report stronger digital literacy also tend to report greater use of innovative teaching and learning practices in the five participating schools.

A possible explanation is that teachers with stronger digital competencies may be better equipped to identify appropriate digital resources, evaluate the usefulness of educational content, select technology that fits instructional objectives, and adapt learning activities to different classroom needs. These competencies may broaden the range of

instructional strategies available to teachers. This interpretation is consistent with the relevance of digital competence to educational practice discussed by López-Gómez, Sáez-López, and Miranda-Perea (2021) and Suryadi, Muslim, and Setyono (2024).

Nevertheless, the coefficient should not be interpreted as proof that digital literacy is a necessary or sufficient condition for learning innovation. Teachers may also innovate through non-digital approaches, and digital tools do not necessarily improve instruction when they are not aligned with learning objectives. Other explanations are also possible. For example, teachers who are already more innovative may have greater motivation to develop their digital skills, while access to devices, internet connectivity, technical support, workload, and school policies may influence both digital literacy and innovation. These factors were not independently examined in the present model.

The larger coefficient for digital literacy therefore indicates a stronger estimated association with learning innovation within this study, not universal superiority over transformational leadership. Moreover, a formal comparison of the coefficients would be required to establish whether their difference is statistically significant. The result supports considering digital professional development as one component of school improvement, while recognizing that its effectiveness may depend on the wider instructional and organizational context.

4.3 Transformational Leadership and Academic Achievement

Transformational leadership was positively associated with academic achievement ($\beta = 0.159$, $p = 0.017$). Although statistically significant, its estimated direct coefficient was smaller than those for teachers' digital literacy ($\beta = 0.396$) and learning innovation ($\beta = 0.273$). This pattern suggests that the relationship between leadership and the measured achievement outcome may be less direct than its relationship with teachers' instructional practices.

One possible explanation is that principals' leadership practices are related to student outcomes through organizational conditions, such as teacher collaboration, professional learning opportunities, resource allocation, and the development of a supportive school climate. These conditions may shape the environment in which teaching and learning take place rather than directly determining individual students' grades. The positive relationship between transformational leadership and learning innovation observed in this study is consistent with this interpretation.

However, organizational climate, teacher collaboration, and resource allocation were not separately tested as mediating variables. Their roles therefore remain possible explanations rather than empirical findings of this study. The smaller direct coefficient should also not be interpreted as evidence that leadership is unimportant. The relationship may depend on the quality of implementation, school conditions, and the extent to which leadership practices are translated into classroom activities. Further research using additional organizational and instructional measures would be needed to examine these possibilities.

4.4 Teachers' Digital Literacy and Academic Achievement

Teachers' digital literacy was positively associated with academic achievement ($\beta = 0.396$, $p < 0.001$). This finding suggests that higher teacher-reported digital literacy was associated with higher achievement scores linked to the participating teachers' teaching assignments. A possible explanation is that digital competencies may help teachers identify learning resources, organize instructional materials, provide varied learning activities, and use digital tools to support assessment and feedback.

The finding is broadly consistent with the relevance of digital competencies to educational practice discussed by Chen (2025) and Khasanah and Yushita (2023). However, the present study measured teachers' digital literacy rather than students' digital literacy. Consequently, explanations involving students' independent use of digital resources or learning autonomy should not be treated as directly tested mechanisms in this study.

The association may also reflect factors not included in the model. For example, teachers with greater access to technology or more supportive school environments may report higher digital literacy and have better opportunities to implement effective teaching practices. Differences in student characteristics, subject content, and classroom conditions may also be relevant to academic achievement. The current results do not establish whether digital literacy itself, the instructional practices associated with it, or other related factors account for the observed relationship. Thus, the findings support further attention to teachers' digital competencies without implying that technology use alone guarantees better student outcomes.

4.5 Learning Innovation and Academic Achievement

Learning innovation was positively associated with academic achievement ($\beta = 0.273$, $p = 0.001$). This finding indicates that higher teacher-reported levels of learning innovation were associated with higher values of the academic-achievement measure used in the study. Innovative teaching practices may provide opportunities to vary instructional activities, encourage student engagement, and adapt learning experiences to instructional objectives. Such practices may be relevant to student learning when they are appropriately designed and implemented.

This interpretation is consistent with the broader discussion of educational transformation and instructional innovation in Timotheou et al. (2022). Nevertheless, the present study did not directly measure the specific classroom processes through which innovation might relate to achievement, such as student engagement, feedback quality, or the effectiveness of particular digital learning activities. It is therefore not possible to determine which forms of innovation were most closely associated with the observed achievement scores.

The relationship should also be considered in light of the measurement approach. Learning innovation was assessed through teacher perceptions, whereas academic achievement was obtained from report-card documentation. This distinction provides some separation between the sources of measurement, but it does not eliminate the possibility of bias or differences in how the measures represent classroom and student outcomes. Further research could examine specific instructional practices and use multiple measures of achievement to clarify the relationship.

4.6 The Mediating Role of Learning Innovation

The mediation analysis identified a positive and statistically significant indirect relationship between transformational leadership and academic achievement through learning innovation ($\beta = 0.076$, $p = 0.027$). A positive and statistically significant indirect relationship was also identified between teachers' digital literacy and academic achievement through learning innovation ($\beta = 0.172$, $p = 0.002$). Both findings support the proposed statistical mediation pathways.

The first indirect relationship suggests that transformational leadership was associated with academic achievement partly through its relationship with learning innovation in the estimated model. This pattern is consistent with the possibility that leadership practices are related to achievement when they coincide with more innovative teaching practices. The second indirect relationship suggests that teachers' digital literacy was associated with academic achievement partly through its relationship with learning innovation. This pattern is consistent with the possibility that digital competencies are linked to instructional practices that are, in turn, associated with achievement.

The indirect coefficient for digital literacy was numerically larger than that for transformational leadership. This difference is consistent with the larger estimated relationship between digital literacy and learning innovation. However, the coefficients alone do not establish that the two indirect effects differ significantly from each other; such a conclusion would require an appropriate statistical comparison.

Importantly, these results demonstrate statistical mediation within the specified model, not a confirmed causal mechanism. The observational, single-period design cannot establish that changes in leadership or digital literacy occurred before changes in learning innovation and subsequent achievement. Other unmeasured factors may also contribute to the observed relationships. Although the direct relationships between transformational leadership and academic achievement, and between digital literacy and academic achievement, remained statistically significant, the pattern is consistent with partial mediation in the estimated model. The mediation findings should therefore be interpreted as evidence supporting the proposed relationships rather than proof that learning innovation causally transmits the effects of leadership or digital literacy to achievement.

4.7 Interpretation of the Explanatory Power

The model produced an R^2 value of 0.771 for learning innovation and 0.621 for academic achievement. These values indicate that transformational leadership and teachers' digital literacy jointly accounted for 77.1% of the variance in learning innovation, while transformational leadership, teachers' digital literacy, and learning innovation jointly accounted for 62.1% of the variance in the academic-achievement measure.

These values describe the explanatory capacity of the specified model within the analyzed sample. They do not mean that the included variables caused 77.1% of learning innovation or 62.1% of academic achievement. The remaining variance may reflect other factors not included in the model, measurement differences, and individual or school-level characteristics. The R^2 values should consequently be interpreted as indicators of explained variance rather than direct estimates of causal contribution.

The explanatory power also needs to be considered alongside the model-fit results. Although the SRMR value met the stated reference threshold, the NFI value of 0.768 and RMS Theta value of 0.174 indicated that not all reported fit indices met the reference criteria used in the original manuscript. The results should therefore be interpreted transparently, recognizing both the variance explained by the model and the limitations indicated by the fit assessment.

4.8 Measurement Considerations and Practical Implications

Three constructs in this study—transformational leadership, teachers' digital literacy, and learning innovation—were measured through teacher questionnaire responses, whereas academic achievement was measured using report-card grades. This approach combines perceived instructional and organizational characteristics with an administrative measure of student performance. However, the report-card scores were associated with the subjects taught by participating teachers, meaning that comparability may depend on subject-specific assessment practices, grading standards, student composition, and school-level procedures.

Although report-card grades provide a practical indicator of academic performance, grades across different subjects and schools may not necessarily represent identical levels of achievement. The available results do not establish whether all scores were standardized or adjusted for differences in grading practices. Accordingly, the academic-achievement measure should be interpreted as the documented grade-based outcome used in this study rather than a fully standardized measure of achievement across all students, teachers, and schools.

The findings nevertheless suggest several practical considerations for the participating schools. First, professional development for teachers could focus on the purposeful use of digital tools, including evaluating digital resources, aligning technology with instructional objectives, and using digital assessment and feedback appropriately. Second, school leaders could support experimentation with teaching practices

by providing opportunities for collaboration, professional learning, and the sharing of instructional experiences. Third, schools could evaluate learning innovation not only by the adoption of technology but also by its relevance to learning objectives and the needs of students.

These recommendations should be applied proportionately to the evidence. The study identifies statistical relationships rather than testing the effectiveness of specific professional-development programs or leadership interventions. School leaders and education policymakers should therefore consider local needs, available resources, teacher readiness, and subject-specific requirements when translating the findings into practice. Evaluation of any resulting initiatives would be necessary to determine whether they improve teaching practices and student outcomes.

Overall, the findings provide evidence of positive statistical relationships among transformational leadership, teachers' digital literacy, learning innovation, and the grade-based academic-achievement measure in the five public senior high schools studied. The contribution of the study lies in examining learning innovation as a statistical mediator within this context. However, the cross-sectional observational design, the use of teacher-reported measures for three constructs, the single-indicator measurement of academic achievement, and the limited geographic setting constrain causal interpretation and generalizability. Future studies could use longitudinal data, more comparable achievement measures, additional school-level variables, and intervention-based designs to examine the proposed mechanisms more directly.

5. CONCLUSION

This study examined the relationships among transformational leadership, teachers' digital literacy, learning innovation, and students' academic achievement in five public senior high schools in Cilegon City. The results showed that transformational leadership and teachers' digital literacy were positively and significantly associated with learning innovation. Both variables also had significant positive direct relationships with academic achievement, while learning innovation was positively and significantly associated with academic achievement. In addition, learning innovation showed significant indirect relationships between transformational leadership and academic achievement ($\beta = 0.076$, $p = 0.027$) and between teachers' digital literacy and academic achievement ($\beta = 0.172$, $p = 0.002$). These findings indicate that learning innovation may represent a relevant pathway linking leadership and teachers' digital literacy with academic achievement within the proposed model. However, given the cross-sectional design, the results demonstrate statistical associations rather than definitive causal effects.

Practically, the findings suggest that school leaders may support learning innovation by fostering transformational leadership practices and strengthening teachers' digital literacy. These efforts may be considered alongside other factors that contribute to students' academic achievement. The findings do not establish that these three constructs are sufficient to improve achievement, as other student, teacher, classroom, and school factors were not included in the model.

Several limitations should be considered when interpreting the results. First, the study was conducted in five public senior high schools in Cilegon City, which may limit the generalizability of the findings to other educational contexts. Second, the study relied on teacher-reported measures of transformational leadership, digital literacy, and learning innovation, while academic achievement was represented by report-card grades for subjects taught by the participating teachers. This combination of data sources may not fully capture individual students' learning experiences or achievement, and the procedure for matching teacher responses with student grades should be clearly documented. Third, respondents were drawn from only five schools, so observations may be clustered within schools. Because the analysis did not account for school-level clustering, the reported statistical significance may not fully reflect this dependence. Finally, the model's RMS Theta value and the exclusion of other potential explanatory variables indicate that the findings should be interpreted cautiously.

Future research should include a broader range of schools, clarify the matching of teacher-level and student-level data, and consider analytical methods that account for students' and teachers' clustering within schools. Longitudinal or other appropriate research designs could also help establish temporal relationships and provide stronger evidence regarding possible causal mechanisms. Further studies may incorporate additional student-, classroom-, and school-level factors to develop a more comprehensive understanding of academic achievement.

Suggestion

Based on these findings and limitations, this study suggests several things. Principals are advised to consistently implement transformational leadership by providing motivation, role models, and support for teachers in developing learning innovations. Teachers are advised to continuously improve their digital literacy competencies through training and independent learning, and implement these competencies in the form of tangible learning innovations in the classroom. Education offices are advised to provide ongoing leadership development programs for principals and digital literacy for teachers, accompanied by the provision of adequate educational technology facilities. Future researchers are advised to expand the research model by adding other variables, such as student learning motivation, school culture, or parental involvement, as well as expanding the scope of regions and educational levels to obtain a more comprehensive picture of the factors that influence student academic achievement.

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