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Transforming Vocational Education Through Deep Learning Ecosystems for Strategic Leadership Stakeholder Engagement and Innovation Capacity

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Abstract

Recently, schools have faced the demands of 21st-century educational transformation and the digital era, necessitating the development of a learning ecosystem model that integrates deep learning. Based on Constructivism Theory and Social Learning Theory, this study aims to analyze the influence of strategic school leadership and stakeholder engagement on the implementation of deep learning through school innovation culture and the development of the learning ecosystem. The study involved a quantitative approach with an explanatory design involving 145 educators at vocational high schools in Indonesia, at educational units implementing deep learning-based learning transformation. The data were collected through a structured questionnaire and subsequently analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings indicate that the success of deep learning implementation is determined by school leadership, stakeholder involvement, a school culture of innovation, and the development of a collaborative and sustainable learning ecosystem. This study provides theoretical contributions to the development of ecosystem-based education models as well as practical recommendations for schools and policymakers in supporting educational transformation in the digital era and 21st-century learning.

1. INTRODUCTION

Twenty-first-century learning requires schools to cultivate critical and independent learners. This shift in the surface learning curriculum, which relies on content-based learning, toward student-centered learning with a deep learning approach (Ito et al., 2025; Ito & Takeuchi, 2022; Kangaslampi et al., 2024), has become a curricular update in various countries (Entwistle, 2023). In Indonesia, deep learning education is also a current educational need (Ambarita et al., 2025; Fitrah et al., 2025). The gap between conceptual learning and the formation of real-life learning experiences has been studied by constructivist learning. Even the formation of tacit knowledge through real-life learning experiences meets the demands of learning outcomes for the development of higher-order thinking skills, including critical, creative, collaborative, reflective, and contextual skills. In global position, education in Indonesia is below the OECD average (Sakhiyya & Rahmawati, 2024; Welch & Aziz, 2024). On the other hand, the Indonesian government’s efforts in implementing deep learning need to be explored and modeled to bridge the process of how policies impact learning outcomes (Lina et al., 2026).

The insufficient ability to provide critical reasoning and build contextual learning experiences is a prominent issue affecting student learning outcomes and must be addressed. Several studies have noted the importance of addressing this issue in improving the quality of human resources, achieving quality of life and health for prosperity and well-being, and even determining a nation's welfare (Runde et al., 2023; Suparno, Purwana, et al., 2023). In addition, a study pointed out that teachers' pedagogical skills in applying methods and media are crucial (Joyce & Calhoun, 2024). Therefore, teachers need to implement the demands of a technology-based educational curriculum and explore learning in depth to create contextual learning experiences.

Concerning Indonesia, vocational high schools (SMKs) totaled 14,265 in 2023, with the highest unemployment rate at 8.63%. Meanwhile, the academic ability test in Mathematics yielded subpar results, with a score of 34.74 on a 100-point scale. The gap between competency and graduates is a concern for developing a curriculum that fosters critical, in-depth reasoning in students. Preliminary works remarked that principals serve as leaders of strategic change in educational units based on curriculum and learning processes (Marshall, 2025; Meyer et al., 2023; Williams, 2023).

In addition, schools need to teach students to think through, process, and implement policies. This condition is determined by the principal’s leadership strategy, which establishes a vision and mission, and leads the achievement of learning outcomes as a joint effort. Educational transformation determines the direction and outcomes of learning through the curriculum, academic climate, school culture, and the provision of educational facilities. All budgets and thinking must focus on classroom learning. This is essential because the ultimate goal of educational policy is the curriculum, where teachers and students interact to shape experiences and change behavior. Several studies have noted that translating vision and innovation into practice and managing change within teacher, academic, and school cultures remain major challenges for effective school leadership, primarily in developing countries where leaders must reduce clerical and repetitive administrative burdens in education (Gonzales & Roberts, 2025; Jakavonytė-Staškuvienė & Barkauskienė, 2023).

The optimization of educational outcomes can also be achieved through the integration of school learning and parenting (Halimah et al., 2026). Schools can implement a nature-based curriculum as a learning medium and align it with the needs of the

industrial sector to enable students to engage in guided, real-world practice. This partnership model requires systematic analysis of both program implementation and outcomes. The learning ecosystem is expected to connect school-based learning with parental involvement as home educators, which further supports students in integrating learning outcomes into daily life. Some studies have noted that learning transformation also requires cultural and learning innovation (Rachmad, 2022; Sliwka et al., 2024a). Hence, schools need to build an academic culture that gives teachers and students space to develop educational processes and thinking skills.

Previous studies have examined several predictors of deep learning implementation. Strategic school leadership has been found to influence school innovation culture (Alzouebi et al., 2025; De Jong et al., 2022; Lu & Chen, 2025) and the development of the learning ecosystem (Benoliel & Schechter, 2023; Hung et al., 2023). Stakeholder engagement has also been associated with school innovation culture (Osobajo et al., 2023) and learning ecosystem development (Tarode & Shrivastava, 2022). Furthermore, a school innovation culture contributes to the development of the learning ecosystem (Zhuang & Liu, 2022) and supports the implementation of deep learning (Sliwka et al., 2024). Learning ecosystem development has also been identified as a direct predictor of deep learning implementation (Andriyani et al., 2025; Nguyen & Tuamsuk, 2022). However, previous studies have not integrated strategic school leadership, stakeholder engagement, school innovation culture, learning ecosystem development, and deep learning implementation into a single empirical model, particularly in the context of vocational schools. This study, therefore, examines the mediating roles of school innovation culture and learning ecosystem development to identify the most effective pathway for implementing deep learning in schools.

This study provides theoretical and practical contributions to educational leadership and curriculum development. First, it develops an integrated model that explains how strategic school leadership and stakeholder engagement influence the implementation of deep learning through school innovation culture and the development of the learning ecosystem. Second, the findings can support policymakers and school stakeholders in designing evidence-based strategies for building a twenty-first-century learning ecosystem. The study also provides empirical insight into how schools can strengthen deep learning through leadership, collaboration, innovation, and ecosystem alignment. The remainder of this paper presents the literature review, research method, findings, discussion, and conclusion.

2. LITERATURE REVIEW

Constructivist learning theory emphasizes that learning is a process of constructing knowledge, understanding the formation of new, verified knowledge (MacLeod et al., 2022; Rachmad, 2025). This learning involves reasoning, critical thinking, and examining learning outcomes using evidence and facts so that students can construct new learning experiences and revise previous knowledge. In terms of learning organization, Bandura (1969) noted in social learning theory that the environment serves as a knowledge builder for achieving learning outcomes (Bandura, 1999; Rumjaun & Narod, 2025). This aspect underscores the importance of schools designing conducive efforts and environments, as well as curriculum tools, to determine learning objectives and media to achieve learning productivity. The different learning processes and outcomes underline the need for a theoretical analysis of both theories through modeling and application. This is expected to provide effective in-depth learning input for schools in their deep learning policies and implementation.

2.1. Deep Learning Implementation

Deep Learning is a learning approach in the development of 21st-century learning (Kovač et al., 2025) to apply higher-order thinking skills to students' thinking abilities. In the process of implementing deep learning, students are involved in problem-solving and creativity. According to Joyce and Calhoun (2024), this is an important learning process in models of teaching, where students are the center of learning to construct knowledge and understanding into verified learning experiences that can answer challenges and problems in everyday life. This method is directed at new situations by providing real situations through the environment and learning media.

Deep learning is a critical thinking process that applies understanding to learning (Yang et al., 2022). A study by Kovač et al. (2025) stated that the deep learning process involves critical thinking and problem-solving, applying what is learned rather than memorizing it. Deep learning involves creativity and collaboration, making it an innovative learning process that can provide real

and meaningful experiences for students (Weng et al., 2023). The learning process with this approach also points out the importance of learning reflection, which can provide a collaborative evaluation of learning outcomes between students and teachers, thus further providing an independent learning process and outcomes.

Some prior investigations have noted that the implementation of deep learning is influenced by school innovation culture and the development of the learning ecosystem (Koul & Nayar, 2021; Perry et al., 2022; Yang & Wang, 2022a). This is because a school's innovation culture can drive teachers and students to develop independent learning and be open to new knowledge. Conversely, a conducive learning environment promotes students to become independent learners and learn to apply their experiences. In addition, deep learning is influenced by school innovation culture and the development of the learning ecosystem, as the academic environment and school culture are essential in shaping positive learning processes and outcomes (Yang & Wang, 2022b). Conversely, a non-conducive school environment and a non-innovative school culture discourage students from exploring independent learning and passively acquiring knowledge from teacher lectures (Feng & Xiao, 2024).

Therefore, it can be concluded that the implementation of deep learning is the application of a learning process that fosters in-depth understanding through the development of critical thinking, problem-solving, collaboration, creativity, and reflection on learning. This can be achieved through critical thinking, problem solving, collaboration, creativity, and reflective learning, which are reflected in the learning process through the level of learning activities that influence analysis and evaluation, students' ability to solve contextual problems, the intensity of group work and interaction between students, the production of creative ideas/solutions, and the practice of reflection on the learning process.

2.2. Strategic School Leadership

The direction of education is determined by leadership and curriculum policies. The principal can be a main role as a leader of change and in achieving learning targets. A structured set of policies within the school system serves as a leadership strategy for the principal in achieving the vision and mission. While strategic school leadership is identified as the principal's ability to formulate the goals of the school organization as an educational institution through a vision, strategy, and policies to improve the quality of learning (Mu'alimin et al., 2026). In 21st-century learning, the principal's achievements within the educational organization are expected to become a sustainable learning organization. A study stated that strategic school leadership also involves how the principal leads change through a vision and mission, the development of a flagship school program, the digitalization of the school system, and learning productivity (Sliwka et al., 2024c), and even the management of school resources and funding to optimize learning by involving teachers.

Strategic School Leadership drives the creation of a school innovation culture and the development of a learning ecosystem (Benoliel & Schechter, 2023b). This is because the principal, as a collaborative and transformational leader, directs the achievement of educational goals through a well-defined vision and mission. An effective leadership strategy is expected to foster innovative learning in both process and outcome. This is because the entire learning process depends on the curriculum structure and even on the teacher's innovation in teaching. In other respects, the principal also plays a significant role in fostering a conducive learning environment.

Strategic School Leadership is the principal's capacity to formulate the vision, strategy, and direction of school development (Eisenschmidt et al., 2025), driving the transformation of learning and innovation, and leading change for the progress of the educational institution he leads. Achievement of strategic school leadership through determining strategic vision and direction, planning school programs, supporting quality learning, Teacher participation in decision making, and Management of educational resources. The application of the leadership strategy is evident in the clarity of the school's learning-oriented vision, the consistency of strategic program implementation, the principal's support for learning innovation, the level of teacher involvement in school policies, and the effectiveness of resource management. Based on this, we can conclude that strategic school leadership is the principal's ability to formulate a vision, strategy, and policy that is oriented towards improving the quality of learning and sustainable school development, which is measured through teacher perceptions regarding the principal's ability to determine a strategic vision, plan school development programs, support learning, involve teachers in decision making, and manage educational resources.

2.3. Stakeholder Engagement

Parents of students, as an important part of school education, need to be involved in supporting various school programs (Hornby & Lafaele, 2023; Topping, 2025). Stakeholder Engagement refers to the level of involvement of parents as stakeholders in educational institutions to support effective learning programs (Leal Filho et al., 2025). This also involves other stakeholders, such as the government, industry, and communities that are directly or indirectly involved in the development of education in schools. Stakeholders in school learning can provide input in improving the relevance and sustainability of education, even student competency in teaching.

Stakeholder engagement influences school innovation culture and the development of the learning ecosystem (Alzouebi et al., 2025; Grunwald et al., 2024). This indicates that stakeholder involvement can encourage schools, through collaborative programs, to develop innovation and promote the development of a learning ecosystem for teachers and students. Various effective collaborative programs can drive all learning stakeholders to achieve educational goals. Active stakeholder involvement can make a real contribution through activities such as practitioner involvement and the utilization of facilities and infrastructure for the learning process. Various programs that can be implemented include parental involvement, community participation, partnerships with the industrial world, government support, and even collaboration with academic institutions.

Thus, stakeholder engagement refers to the level of involvement of stakeholders such as parents, communities, government, industry, and educational institutions in supporting the educational process and school development. Stakeholder Engagement is measured through teacher perceptions regarding the level of involvement of parents, communities, industry, government, and academic institutions in supporting learning activities at school. This measurement can be reflected in the frequency and quality of school interactions with parents, collaborative programs with local communities, industry involvement in learning, and cooperation with universities/educational institutions.

2.4. School Innovation Culture

School culture is crucial in fostering creative learning (Page et al., 2023). School culture needs to be innovative to drive change and school progress. School innovation culture is identified as the values and norms and their implementation in educational organizations to encourage creativity and innovation (Achdiat et al., 2023; Alt et al., 2023), which can be implemented through collaborative learning and the application of new ideas to solve problems and gain new insights from learning. School innovation culture is also identified as the application of learning innovation through openness to change to develop knowledge through new experiments so that students can gain contextual learning experiences (Lu & Chen, 2025).

In teacher leadership and school culture, a school innovation culture can foster a positive learning ecosystem (Suparno, Firstianto, et al., 2023). The values of openness in learning shift students' paradigm toward thinking and discovering new ways to solve learning problems (Almulla, 2023a) and foster the development of a good learning ecosystem. As the school's main strategy for implementing learning objectives. The culture of innovation developed by schools is not easy, because it requires preparing students to be open-minded to new things and even verifying new knowledge with students and teachers in an adaptive manner.

Accordingly, it can be identified that school innovation culture is the values, norms, and practices in the school environment that affects creativity and the application of new ideas in the learning process. School innovation culture is implemented through support for learning innovation, openness to change, collaboration, knowledge sharing, experimentation and reflection. Its measurement can be developed through the level of school support for new ideas, flexibility in adopting new learning methods, intensity of teacher collaboration, practice of sharing experiences and good practices, and frequency of trial of innovative learning methods.

2.5. Learning Ecosystem Development

Effective learning processes require a supportive ecosystem (Ortega et al., 2025). A conducive learning environment is prominent for teachers and students through the integration of resources and partnerships that support learning (Zhou, 2025). Learning ecosystem development is the development of an integrated learning system that connects actors and the learning environment (Regmi, 2024). This is a strategic effort by schools to improve learning outcomes and quality.

Learning ecosystem development influences the quality of learning, including the implementation of deep learning as an approach in the learning process (Samyong et al., 2024). A conducive environment will enable students to collaboratively achieve learning outcomes, deeply understand them, and even reconstruct them into new experiences through adequate media and infrastructure (Oktafiyana et al., 2025). In other aspects, the learning environment needs to be well-designed, because students' learning will develop if it is conducive and has a competitive and democratic academic learning climate.

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H1. SSL positively impacts on SIC

H3. SSL positively impacts on LED

H2. SE positively impacts on SIC

H4. SE positively impacts on LED

H5. SIC positively impacts on LED

H6. SIC positively impacts on DLI

H7. LED positively impacts on DLI

H8. SIC mediates the impact of SSL on DLI

H9. SIC mediates the impact of SE on DLI

H10. LED mediates the impact of SSL on DLI

H11. LED mediates the impact of SE on DLI

H9. SIC and LED mediates the impact of SSL on DLI

H12. SIC and LED mediates the impact of SE on DLI

3. METHODOLOGY

This study explores the causal relationship and its strength among research variables using reliable, empirically validated data. A deep learning implementation research model was developed by analyzing Learning Ecosystem Development (LED), School Innovation Culture (SIC), Stakeholder Engagement (SE), and Strategic School Leadership (SSL) as predictor and mediator variables. The research variables were analyzed using exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to model deep learning implementation in Vocational High Schools (SMK).

3.1. Participants

The population in this study was all 250 vocational high school teachers who are members of the Subject Teachers' Conference (MGMP) in Jakarta. The sample size was determined using Slovin's formula with a 5% error rate, yielding a minimum of 154 respondents. The sampling technique used was proportional random sampling to ensure that each member of the population had an equal opportunity to be selected as a respondent. However, of the total questionnaires distributed, only 147 respondents had complete and suitable data for processing, and this number was used as the final sample in this study.

3.2. Data Analysis

The data was further processed using Partial Least Squares (PLS). PLS is a powerful analytical method because it is not based on many assumptions, such as normal distribution of data and a small sample size. PLS-SEM is used to develop or build theories (prediction orientation). PLS can be used to describe whether there is a relationship between latent/prediction variables (Kono & Sato, 2023). This study has a complex model and a limited sample size, so SmartPLS software was used for data analysis.

Test the validity and reliability of the construct measurement model with the criteria of Cronbach's score equal to or higher than 0.6 (Hair, Black, et al., 2019) and acceptable more than 0.5 and when equal to 0.7 (Hair Jr et al., 2017). Next, hypothesis testing is carried out by testing the prerequisites of data normality, linearity, and significance of regression and correlation coefficients. To test the suitability of the model, several measurement criteria must be met with a probability > 0.5 (Schermelleh-Engel et al., 2003), RMSEA < 0.05, CFI > 0.95 (Hu & Bentler, 1999), and CMIN/DF value < 2 (Tabachnick & Fidell, 2007). The influence of mediating variables can measure the partial and total influence of research with moderator and mediator variables (Hayes, 2013).

3.3. Outer Model Evaluation

The outer measurement model defines how each indicator block relates to each manifest variable in the form of indicators or instruments related to the latent variable (Leguina, 2015). Latent variables in PLS-SEM are quantitative variables that cannot be observed directly but can be inferred using mathematical methods from other directly measured variables. Meanwhile, manifest variables are defined as variables whose quantitative magnitude can be known directly, which in this study is the respondent's score on each questionnaire (Hair, Risher, et al., 2019).

3.4. Inner Model Evaluation

This model testing is the development of a theory-based concept and model to analyze the relationship between exogenous and endogenous variables as described in the conceptual framework. Exogenous latent variables act as independent variables, while endogenous latent variables act as variables that were previously dependent variables (Bollen, 2002). Therefore, structural model testing is evaluated using R-square, ƒ-square, and variance inflation factor (VIF) (Latan & Ramli, 2013; Sarstedt et al., 2014).

3.5. Hypothesis Testing

Analyzing the mediation effect requires observing changes in the influence of direct and indirect relationships (Wootton, 1994). This indirect effect aims to test the hypothesis of an indirect effect of the independent variable on the dependent variable mediated by the variable as seen from the bootstrapping results. The specific indirect effect column aims to answer how the role of the mediating variable influences the independent variable on the dependent variable. To determine the relationship between the effects of the proposed model in the study, it is tested through EFA and continued with CFA. Predictor variables, outcome variables, and mediator variables are arranged as a standard procedure for testing theories through hypotheses (Hair & Alamer, 2022), a way to develop theory, and promote a better scientific understanding of the mechanisms of the relationship between independent variables (predictors) and dependent variables (outcome variables).

4. RESULTS AND DISCUSSION

4.1. Respondents

Based on the research results, a data description is presented as a general overview of the data processing outcomes for the five research variables in the development of the DLI model. The research data are primary data on DLI and LED variables, obtained through a behavioral scale questionnaire using a semantic differential scale (Osgood, 2019), with options from 1 to 5. With criteria where 1 is rare or low, and 5 is frequent or high. Meanwhile, the primary data for the social attitude variables SIC, SE, and SSL were obtained through a Likert-scale questionnaire with response options from 1 to 5 (Maruf, 2023). Furthermore, respondent data is presented in Table 1.

Table 1
Characteristics of Research Respondent Data

Description		Number of Samples	Percentage
Gender	Male	83	56.5
	Female	64	43.5
Age	25–34	51	34.7
	35–44	43	29.3
	45–54	30	20.4
	55 and more	23	15.6
Education	Bachelor	88	52.4
	Master	53	33.3
	Doctoral	6	14.3
Training	Yes	109	74.1
	No	38	25.9
Working Experience	1–5	39	26.5
	5–10	42	28.6
	11–20	40	27.2
	> 20	26	17.7

As shown in Table 1, the majority of respondents were male, 83 people (56.5%). The age range of respondents was dominated by the 25–34 years old age group (51 people, 34.7%), and the age range of 55 years and above, who were approaching retirement, was 23 people (15.6%). In terms of education, the majority of respondents had a Bachelor's degree (88 people (52.4%), and a few had doctorates (6 people (14.3%). The majority of respondents had participated in training (109 people, 74.1%), with a work period dominated by the 5–10 years range (42 people, or 28.6%).

4.2. Evaluation of the Outer Model

The external model measurement evaluation was used to assess the model's validity and reliability, as well as its discriminant validity. Based on Table 2, there are five research variables: DLI (10 indicators) with 7 valid statements and 3 dropped items; LED (8 indicators) with 6 valid statements and 2 dropped items; SIC and SE (7 valid statements and 2 dropped items); and SSL (9 statements) with 7 valid statements and 2 dropped items. Invalid items were removed or excluded so that all items had factor loadings > 0.70. Thus, all statement items in DLI in Vocational High Schools study have met convergent validity. The complete external model measurement results can be seen in Table 2.

Table 2
Outer Measurement Results of the Research Model

Code	Questionnaire Item	λ	α	CR	AVE
Deep Learning Implementation (DLI)					
DLI1	Teachers ask students to analyze and evaluate problems before drawing conclusions.	0.908	0.957	0.965	0.796
DLI2	Teachers assign real-life problem-based assignments for students to solve.	0.904			
DLI3	Students discuss in groups to deepen their understanding.	0.920			
DLI4	Teachers encourage students to generate and present creative ideas.	0.915			
DLI6	Teachers ask students to reflect on their learning process.	0.890			
DLI7	Teachers relate learning material to students' real-life contexts.	0.869			
DLI8	Teachers provide feedback that helps students deepen their understanding.	0.835			
Strategic School Leadership (SSL)					
SSL1	The principal communicates the vision for improving learning clearly and consistently to teachers.	0.932	0.976	0.980	0.873
SSL2	The principal establishes a learning innovation strategy, accompanied by measurable targets and action plans.	0.937			
SSL4	The school facilitates training and mentoring to improve the quality of teacher learning.	0.937			
SSL5	The principal actively involves teachers in the planning and evaluation of academic policies.	0.936			
SSL6	The principal allocates resources appropriately to support the implementation of innovative learning.	0.935			
SSL7	The principal monitors the implementation of learning and uses the results for continuous improvement.	0.925			
SSL8	The principal builds collaborations with external parties to support learning innovation.	0.938			
Stakeholder Engagement (SE)					
SE1	Parents are involved in learning activities at school.	0.819	0.958	0.964	0.793
SE2	Schools involve stakeholders in evaluating and planning learning programs.	0.919			
SE3	Schools establish partnerships with industry or external organizations.	0.894			
SE4	Schools receive government support in developing learning.	0.904			
SE5	Schools collaborate with universities or other educational institutions.	0.896			
SE6	Schools regularly communicate student learning progress to parents.	0.929			
SE7	Schools involve stakeholders in evaluating and planning learning programs.	0.867			
School Innovation Culture (SIC)					
SIC1	Schools encourage teachers to try new learning methods.	0.886	0.958	0.965	0.797
SIC2	Teachers are encouraged to be open to changes in the learning process.	0.889			
SIC3	Teachers often collaborate to develop innovative learning strategies.	0.916			
SIC4	Teachers actively share learning experiences with colleagues.	0.912			
SIC5	Schools provide space for teachers to experiment with learning.	0.908			

Code	Questionnaire Item	λ	α	CR	AVE
Deep Learning Implementation (DLI)					
SIC6	Schools recognize innovative learning practices implemented by teachers.	0.864			
SIC7	Schools provide dedicated time for teachers to collaborate on developing learning innovations.	0.872			
Learning Ecosystem Development (LED)					
LED1	Technology is used effectively in the learning process at school.	0.936	0.960	0.968	0.833
LED2	The school provides a learning environment that supports collaboration between students and teachers.	0.916			
LED3	The school provides a variety of learning resources that support in-depth learning.	0.905			
LED4	The school has a network of partnerships that support learning activities.	0.919			
LED6	The school encourages continuous learning for teachers and students.	0.896			
LED7	The school provides digital platforms to support student interaction and learning.	0.903			

The AVE values of the DLI, LED, SIC, SE, and SSL variables are 0.972, 0.831, 0.829, 0.796, and 0.829, all > 0.50, indicating that these variables meet discriminant validity. Composite Reliability values (0.972, 0.971, 0.959, 0.967, and 0.975) and Cronbach's Alpha values (0.967, 0.966, 0.949, 0.959, and 0.971) > 0.70, thus meeting composite reliability. Thus, the DLI, LED, SIC, SE, and SSL variables meet discriminant validity. The results of the complete discriminant validity test and the goodness-of-fit evaluation results of the measurement model can be seen in Table 3.

Table 3
Discriminant Validity Test Results

Variable	DLI	LED	SIC	SE	SSL
Deep Learning Implementation (DLI)	0.892				
Learning Ecosystem Development (LED)	0.939	0.913			
School Innovation Culture (SIC)	0.897	0.917	0.893		
Stakeholder Engagement (SE)	0.825	0.858	0.902	0.890	
Strategic School Leadership (SSL)	0.868	0.883	0.904	0.864	0.934

Table 4
Goodness of fit evaluation results

Indicator	Saturated Model	Estimated Model
SRMR	0.052	0.052
d_ULS	1.585	1.596
d_G	2.561	2.568
Chi-Square	1703.845	1704.213
NFI	0.791	0.791

4.3. Evaluation of the Inner Model

In evaluating the structural model, a collinearity test is conducted to assess whether the variables are highly collinear. The VIF value must be less than 5.00. The VIF of the DLI, LED, SIC, SE, and SSL variables is < 5.00, so there is no collinearity, and all indicators of the tested constructs are valid. The R-Square level test to see the strength of accuracy or prediction, obtained R2

values of the DLI variable (0.889), LED (0.858), and SIC (0.875) means 88.9%, 85.8%, and 87.5% of the variance in DLI, LED, and SIC can be explained by the research variables at a moderate level. In testing the effect size/influence (f2) of each predictor latent variable in the structural model, it was found that the f2 value of LED (0.765) and SIC (0.301), which shows a large effect size. While the f2 value of SE (0.463) and SSL (0.491) shows a medium-sized effect.

The comprehensive assessment of the proposed model's fit was conducted using the standardized root mean square residual (SRMR), discrepancy metrics (d_ULS and d_G), Chi-square statistic, and the normed fit index (NFI). As presented in Table 4, the SRMR was recorded at 0.052 for both the saturated and estimated models, which is under the suggested maximum of 0.08, signifying a good model fit. Additionally, the discrepancy values of d_ULS at 1.596 and d_G at 2.568 imply that the model is a commendable approximation. Although the NFI of 0.791 fell short of the recommended threshold of 0.90, it still reflects a moderate degree of model fit. Since PLS-SEM focuses mainly on predictive capability rather than overall fit, the goodness-of-fit metrics obtained indicate that the structural model is adequate and ready for further hypothesis testing.

4.4. Hypothesis Testing

Based on the results of the structural model test in this study, it was found that 12 relationships between variables had t-values greater than 1.97. Therefore, it can be concluded that all variable relationships in the hypothesis are significant and can also be analyzed for mediation effects. The following are the results of data processing for the Deep Learning Implementation model using PLS-SEM (see Table 5).

Table 5
Hypothesis Testing

Hypothesis Testing	Variable Relations	Original Sample	Sample mean	Standard deviation	T-Value	P Value	Decision
H1	SSL → SIC	0.492	0.487	0.067	7.301	0.000	Accepted
H2	SSL → LED	0.559	0.559	0.102	5.501	0.000	Accepted
H3	SE → SIC	0.477	0.482	0.066	7.224	0.000	Accepted
H4	SE → LED	0.375	0.374	0.110	3.399	0.001	Accepted
H5	SIC → LED	0.584	0.579	0.121	4.833	0.000	Accepted
H6	SIC → DLI	0.655	0.651	0.098	6.661	0.000	Accepted
H7	LED → DLI	0.728	0.727	0.082	8.840	0.000	Accepted
H8	SSL → SIC → DLI	0.113	0.112	0.043	2.659	0.008	Accepted
H9	**SE → SIC → DLI**	**0.070**	**0.066**	**0.090**	**0.776**	**0.438**	**Rejected**
H10	SSL → LED → DLI	0.198	0.205	0.084	2.364	0.018	Accepted
H11	SE → LED → DLI	0.110	0.111	0.045	2.439	0.015	Accepted
H12	SSL → SIC → LED → DLI	0.209	0.204	0.055	3.828	0.000	Accepted
H13	SE → SIC → LED → DLI	0.203	0.203	0.058	3.498	0.001	Accepted

Note. Deep Learning Implementation = DLI; Learning Ecosystem Development = LED; School Innovation Culture = SIC; Stakeholder Engagement = SE; Strategic School Leadership = SSL

As illustrated in Table 5, this study proposes 13 hypotheses, of which 12 are accepted, and one is rejected. SSL has a positive and significant effect on SIC (0.492) and LED (0.559). Indeed, SE has a positive and significant effect on SIC (0.477) and LED (0.375). Furthermore, SIC has a positive and significant effect on LED (0.584) and DLI (0.655), while LED has a positive and significant effect on DLI (0.728) as the largest direct influence on DLI. The mediation estimation shows that SIC mediates the relationships between SSL and DLI, but it fails to mediate the relationship between SE and DLI. In addition, LED mediates SSL and DLI, as well

as SE and DLI. The serial mediation analysis shows that SSL and SE can enhance DLI through the pathway of SIC and LED. A complete overview of the PLS hypothesis testing can be seen in Fig. 1.

The finding shows that SSL has a positive and significant effect on SIC. The fundamental explanation for this result is that SSL can foster a culture of innovation within the school environment. A principal who can articulate a vision and encourage adaptive change will create an organizational environment open to learning and innovation. This finding supports the Constructivism theory, which focuses the importance of a learning environment that supports active and collaborative knowledge building (Almulla, 2023b; Vijayakumar Bharathi & Pande, 2025). Furthermore, the research findings also strengthen the Social Learning Theory, which explains that an innovative culture is formed through social interaction and modeling roles within educational organizations (Koutroubas & Galanakis, 2022).

This study also remarks that SSL had a positive and significant effect on LED, indicating that effective school leadership can create an adaptive and sustainable learning ecosystem. In this regard, SSL is prominent in integrating resources, technology, collaboration, and organizational support to deal with a learning environment that supports DLI. This finding aligns with prior studies regarding the concept of the learning ecosystem, which emphasizes the importance of integrating various educational elements (Nguyen & Tuamsuk, 2022; Ortega et al., 2025) in supporting learning transformation. This is in line with this study, which found a positive and significant effect of SSL on DLI, mediated by LED.

Furthermore, SE has a positive and significant effect on SIC and LED. These results indicate that the active involvement of teachers, parents, communities, and other educational stakeholders can strengthen a school's culture of innovation. Stakeholder involvement can also support the development of a learning ecosystem. The higher the participation and collaboration among stakeholders, the greater the school's ability to develop innovative, deep-learning-oriented learning (Sliwka et al., 2024d). This finding supports the Social Learning Theory, which posits that learning occurs through social interaction and environmental participation (Li et al., 2023; Ting, 2023). However, SE has a positive but insignificant effect on DLI when mediated by SIC. This indicates that the role of educational stakeholders in influencing the deep learning process has not yet been translated into a culture of learning innovation. The school’s learning process and culture of innovation need to be developed independently by schools.

SIC has a positive and significant effect on both LED and DLI. A school's culture of innovation fosters a learning environment that is more open to change, collaborative, creative, and reflective. These conditions support the implementation of deep learning, which emphasizes critical thinking, problem-solving, creativity, and meaningful learning. Thus, a culture of innovation is an important foundation for transforming 21st-century learning. Furthermore, LED has the greatest positive and significant effect on DLI. Prior scholars indicate that the success of deep learning implementation is determined by the quality of the learning ecosystem built by the school (Nguyen & Tuamsuk, 2022; Tuamsuk et al., 2023). An effective learning ecosystem allows for technology integration and active interaction between teachers and students.

The results of the mediation test indicate that SIC mediates the effect of SSL on DLI, with a significant positive indirect effect. This means that strategic school leadership first establishes a school culture of innovation, which in turn encourages the implementation of deep learning. Furthermore, the serial mediation path of SSL on DLI, with SIC and LED as mediators, was also found to be significant, indicating that a school culture of innovation can strengthen the development of a learning ecosystem before increasing the implementation of deep learning (Zhuang & Liu, 2022b). Similar findings were observed for the effect of SE on DLI via SIC and LED. This is in agreement with a prior study that a culture of innovation and a learning ecosystem are important mechanisms in the process of deep learning-based educational transformation (Do et al., 2024).

5. CONCLUSION

The results indicate that strategic school leadership has a positive and significant effect on school innovation culture and the development of the learning ecosystem. Stakeholder engagement also has a positive and significant effect on school innovation culture and learning ecosystem development. Furthermore, school innovation culture has a positive and significant effect on learning ecosystem development, and learning ecosystem development has a positive and significant effect on deep learning implementation. This study also proves that school innovation culture and learning ecosystem development mediate the

influence of strategic school leadership and stakeholder engagement on deep learning implementation, both partially and through serial mediation.

This study underscores the importance of strengthening strategic school leadership, increasing stakeholder collaboration, and developing a school innovation culture to create an adaptive, collaborative, and sustainable learning ecosystem that supports the implementation of deep learning in the era of digital education transformation. Theoretically, this research contributes to the development of constructivism and social learning theory in the context of educational transformation in the digital era (Mhlanga, 2023). This research confirms that the implementation of deep learning can be explained by individual factors, strategic leadership, organizational culture, social engagement, and the development of a comprehensive learning ecosystem. Practically, the research findings provide implications for school principals and policymakers to strengthen a culture of innovation and the development of an adaptive learning ecosystem to support the transformation of 21st-century education.

However, this study has limitations, as it does not yet reflect long-term changes in deep learning implementation. The number and scope of respondents are still limited, so generalizations of the results require caution. The study variables also did not include other factors such as technological readiness, teacher competence, infrastructure support, and student engagement. Furthermore, the use of questionnaires enhances subjectivity in respondents' responses during data collection. Future researchers are advised to expand the research model by adding variables such as digital readiness, teacher competence, student engagement, and technological support to obtain a more comprehensive model of deep learning implementation. Furthermore, the scope of respondents and the research context needs to be expanded to include various levels and educational areas to ensure the generalizability of the results.

DECLARATIONS

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Clinical trial number

Not applicable.

Ethics approval and consent to participate.

This study was approved by the Ethics Committee of Universitas Negeri Jakarta under approval No. 1472/UN39.14/PT.01.05/IX/2026. The study was conducted in accordance with the ethical guidelines and regulations of the Ethics Committee of Universitas Negeri Jakarta. All participants were informed about the purpose and procedures of the study and provided voluntary informed consent to participate.

Consent to publish

Not applicable. This study does not contain any individual person’s data or identifiable information requiring consent for publication.

Authors’ contributions

Supadi Supadi and Suparno Suparno conceived and designed the study, including the development of its conceptual framework. Tarma Tarma and Gelar Gelora Mestika contributed to the technical aspects of the study and data collection. Evitha Soraya contributed to the data collection and research implementation. Suparno Suparno drafted the manuscript. Bagus Shandy Narmaditya contributed to the critical review and revision of the manuscript. Suparno Suparno and Bagus Shandy Narmaditya revised the manuscript for publication. All authors reviewed and approved the final version of the manuscript.

Data Availability

The datasets generated and analyzed during the current study are not publicly available due to ethical considerations and participant confidentiality but are available from the corresponding author upon reasonable request.

Informed consent

Informed consent was obtained from all participants prior to their participation in the study.

Competing interests

The authors declare that they have no competing interests.

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Figures

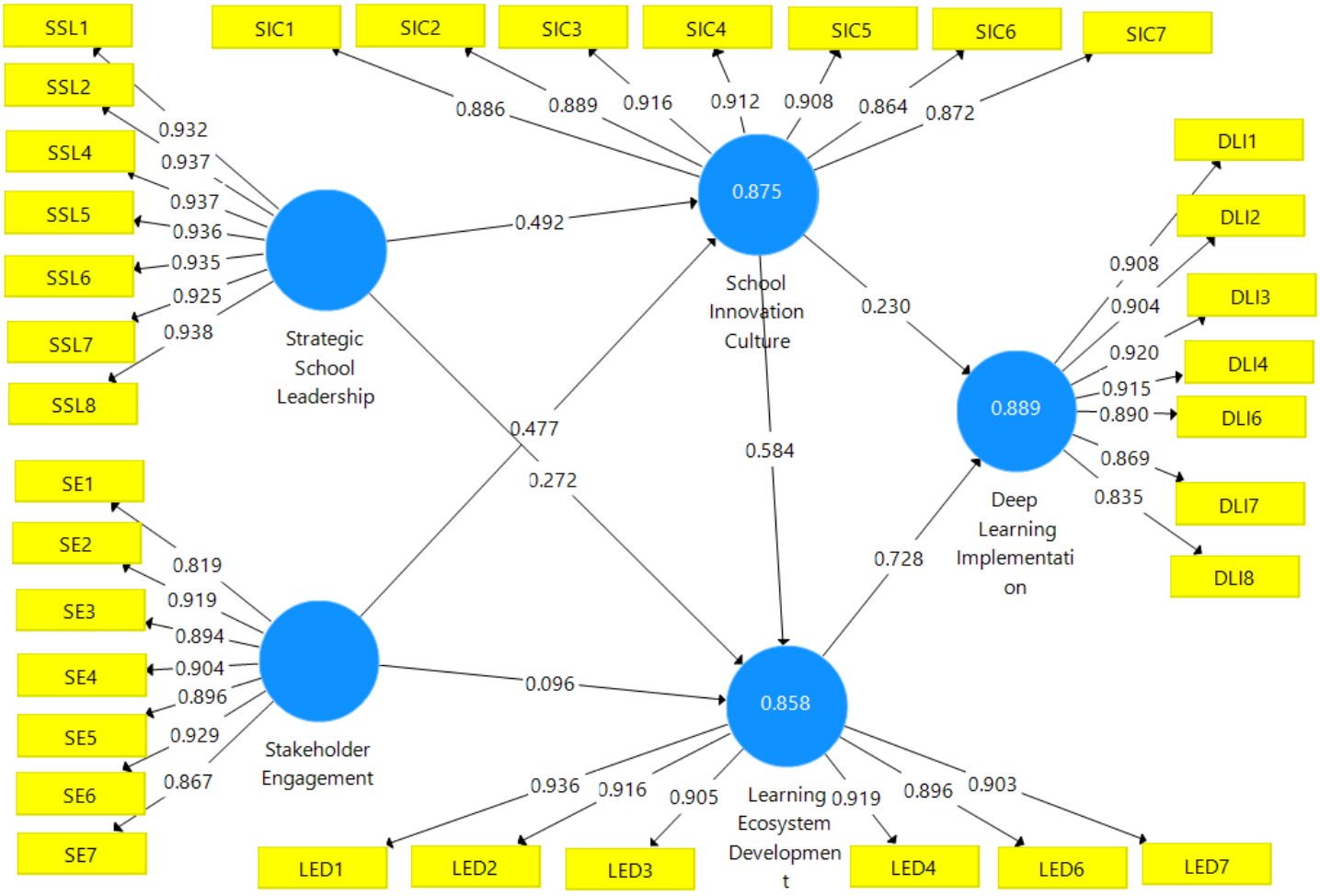


Figure 1

Structural Model