

Building 21st-Century Learning Performance through Digital Ecosystems and Cognitive Agility of Elementary School Teachers in Serang City

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Abstract

The performance of 21st-century learning at the elementary school level demands a robust integration of critical thinking, creativity, collaboration, and communication skills. This study aims to examine a causal model for strengthening 21st-century learning performance through digital learning ecosystem maturity and teacher cognitive agility, while evaluating the mediating roles of adaptive instructional capacity and instructional implementation effectiveness. A quantitative approach with a causal associative design was applied to 51 elementary school teachers in Serang District, Serang City, selected using convenience sampling technique. Data analysis was conducted using Structural Equation Modeling-Partial Least Squares (PLS-SEM) via SmartPLS software. The structural model evaluation results indicated that digital ecosystem maturity and teacher cognitive agility have a significant direct positive effect on 21st-century learning performance, with cognitive agility emerging as the most dominant predictor. Furthermore, the mediation test proved that adaptive instructional capacity and instructional implementation effectiveness function significantly as dual-mediating mechanisms within the causal framework. The combination of all variables in this model successfully explains 64.2% of the variance in 21st-century learning performance. This study implies the critical importance of developing teachers' mental agility and adaptive teaching capacities alongside the fulfillment of schools' digital infrastructure.

Keywords: *Adaptive Instruction; Digital Ecosystem; PLS-SEM; Teacher Cognitive Agility; 21st-Century Learning Performance.*

INTRODUCTION

Contemporary education is undergoing a fundamental paradigm shift, where the primary focus of learning is no longer simply the transfer of knowledge but rather the strengthening of adaptive competencies relevant to global dynamics. 21st-century learning performance demands a comprehensive integration of critical thinking skills, creativity, collaboration, and communication skills. At the elementary school level, achieving this quality of learning forms a crucial foundation for subsequent stages of education. Therefore, the efficiency and effectiveness of teacher instructional performance in the classroom must be strategically directed to stimulate an innovative, interactive, and student-centered learning environment.

However, the reality on the ground often reveals a significant discrepancy between curriculum ideals and their practical implementation. Elementary school teachers,

particularly in developing urban areas like Serang City, frequently face structural and cultural challenges in adopting modern learning standards (Fauzia et al., 2026). The rapid digital transformation has not been fully matched by widespread pedagogical readiness. Many classroom learning practices are still trapped in conventional methods, where interactions are one-way and the use of information technology-based media is limited to administrative tools, not as a catalyst for higher-level thinking (Mahdiyah et al., 2026).

One of the root causes of the suboptimal performance of 21st-century learning lies in the maturity of the digital learning ecosystem within the school environment. A mature digital ecosystem ideally encompasses not only the availability of hardware and internet networks, but also the availability of integrated platforms, supportive school policies, and a culture of collective digital literacy (Rahman et al., 2026). Field evidence suggests that variations in infrastructure quality and weak governance of the digital ecosystem at the elementary school level prevent the enormous potential of educational technology from being transformed into superior academic performance (Hanafiah, 2025).

On the other hand, an internal factor within educators that plays a crucial role but is often overlooked is teacher cognitive agility (Susanti et al., 2026). In an educational environment rife with policy changes and complex student characteristics, teachers are required to possess the mental flexibility to quickly shift instructional strategies when planned methods are ineffective. When teachers have limited cognitive agility, they tend to be resistant to innovation, stutter when solving unexpected classroom problems, and struggle to connect subject matter to the concrete realities of 21st-century life (Wamilda & Balgwa, 2026).

These limitations in the digital ecosystem and teachers' cognitive flexibility directly cripple teachers' adaptive instructional capacity. As the first pillar of mediation, adaptive capacity is a teacher's ability to map the diversity of student characteristics, learning styles, and speed of understanding, and then align the learning direction in real time (Nwachukwu et al., 2025). Without a mature ecosystem modality and agile cognition, teachers will struggle to differentiate learning (Rustiyana, 2025). Consequently, fulfilling students' inclusive learning rights and developing dynamic instructional personalities fails to materialize in elementary school classrooms.

The knock-on effect of this weak adaptive capacity results in low instructional implementation effectiveness. Effective implementation is characterized by well-organized classroom management, high levels of active student engagement, and optimal achievement of assessment targets (Wardani et al., 2025). When the learning process in elementary schools fails to be implemented effectively and meaningfully, the classroom climate becomes un conducive (Darmawan et al., 2026). This condition causally blocks student potential, making it difficult to stimulate competency outcomes such as critical thinking and original creativity.

Although numerous studies have been conducted on teacher competency and educational technology, most previous research tends to examine these variables separately (Jamun et al., 2020) or in simple linear models (Sukardi et al., 2023). There is a significant gap in research regarding how digital ecosystem variables and teacher cognitive agility work simultaneously to influence 21st-century learning outcomes through a dual mediating structure: adaptive capacity and implementation effectiveness. Moreover, empirical studies that capture these causal dynamics at the locus of elementary school teachers in developing provincial government centers such as Serang City are still very rare, even though this region has unique sociological characteristics and digital adaptation challenges.

The novelty of this research lies in the development of a comprehensive causal model that integrates aspects of the digital environment (external) and aspects of teacher cognitive capacity (internal) as primary predictors. This study positions adaptive instructional capacity

and implementation effectiveness as dual-mediating mechanisms explaining the transmission of influence from school readiness and teacher agility toward the realization of comprehensive 21st-century learning performance. Using a variance-based Structural Equation Modeling (PLS-SEM) approach, this model is able to simultaneously and robustly examine the complexity of these relationships, even within efficient sample limitations.

Based on the background and gap analysis above, the primary objective of this study is to empirically test and analyze a causal model for strengthening 21st-century learning performance through the influence of digital learning ecosystem maturity and teacher cognitive agility, both directly and indirectly through the mediating role of adaptive instructional capacity and the effectiveness of learning implementation among elementary school teachers in Serang District, Serang City. The results of this study are expected to provide theoretical contributions to the development of elementary education management and provide practical recommendations for policymakers and principals in designing integrative teacher professional quality improvement programs.

21st-century learning performance is the accumulation of the effectiveness, quality, and outcomes of instructional processes intentionally designed to foster future competencies in students. At the elementary school level, this performance is no longer measured solely on the mastery of low-level cognitive material, but rather on the extent to which teachers are able to create a classroom climate that stimulates the four pillars of core competencies: critical thinking, creativity, collaboration, and communication. Educators with high 21st-century performance are characterized by their ability to facilitate student-centered learning, based on real-world problem-solving, and utilize authentic assessments that comprehensively capture the development of students' soft skills (Adeoye et al., 2024). Strengthening this performance is a cutting-edge orientation in elementary education management to produce a generation with global competitiveness (Nurbuana & Sirozi, 2025).

The maturity of a digital learning ecosystem reflects the level of readiness, integration, and sustainability of information technology utilization within educational institutions. This ecosystem encompasses more than just the physical infrastructure, such as the availability of internet access or computer equipment at school. It is a superstructure that involves a dynamic interaction between the availability of quality digital content, integrated learning platforms (Nguyen & Tuamsuk, 2022), adaptive school regulations, and the digital culture readiness of all school members, including principals, teachers, and parents (Farrell et al., 2024). When a school's digital ecosystem reaches its full maturity stage, technology transforms into a natural and supportive environment for teachers to explore varied, interactive, and cutting-edge teaching methodologies.

Teacher cognitive agility is the mental capacity and psychological flexibility of an educator to process new information, adapt to rapid environmental changes, and shift thinking strategies when faced with complex or unexpected instructional situations. Amidst the dynamics of the curriculum and the diverse characteristics of elementary school students, cognitive agility is a crucial internal asset for teachers (Costa et al., 2014). Cognitively agile educators avoid being trapped in rigid pedagogical routines; they are able to engage in instant critical reflection, address technical challenges in the classroom as opportunities for innovation, and possess the intellectual openness to continually update their professional knowledge in line with current developments (Paul et al., 2020).

Adaptive instructional capacity refers to a teacher's dynamic competence in adjusting material structure, delivery speed, level of support, and learning methods based on individual mapping of students' characteristics, learning modalities, and initial understanding (Martin et al., 2020). At the elementary school level, the need for adaptive teaching is particularly high given the highly variable range of children's psychological and cognitive development.

This capacity requires teachers to have the ability to conduct continuous formative assessments during the learning process and utilize them directly to reengineer classroom interactions. This instructional adaptability positions teachers not as mechanical curriculum implementers, but as responsive and inclusive learning designers (Yono et al., 2026).

The effectiveness of learning implementation is the degree of success of implementing a learning plan in a real classroom, as measured by the optimization of classroom management, the high level of active student involvement in learning activities, and the efficient achievement of established competency indicators (Liu et al., 2025). The key to effective implementation lies in the teacher's ability to orchestrate all components of learning—from time allocation, student behavior management, media use, to strengthening a conducive classroom climate. When learning is implemented effectively, elementary school classrooms will become productive ecosystems, where learning distortions can be minimized and the transfer of meaningful learning experiences can take place optimally (Judijanto et al., 2025).

METHODS

Research Design

This study uses a quantitative approach with a causal associative research design. This method was chosen to empirically test and prove the causal relationship model and the direct and indirect influence paths of exogenous variables on endogenous variables mediated by two intermediary variables. The causal structure in this study involves five variables, namely Digital Learning Ecosystem Maturity (X1) and Teacher Cognitive Agility (X2) as independent variables; Adaptive Instructional Capacity (Y1) and Instructional Implementation Effectiveness (Y2) as mediating variables; and 21st Century Learning Performance (Z) as the main dependent variable.

Population, Sampling Technique, and Data Collection

The target population in this study was all elementary school teachers working in Serang District, Serang City. Given the population's characteristics, which are spread across various educational institutions, the sampling technique used was non-probability sampling with a convenience sampling approach, to ensure efficient data collection in a developing urban area. A valid sample size was collected in this study of 51 respondents. Based on the variance-based Structural Equation Modeling (SEM) methodology, this sample size met the eligibility criteria for testing using the 10-times rule, where the minimum sample size is based on the largest number of structural paths leading to a single endogenous variable in the model.

Primary data collection was conducted digitally through a structured questionnaire distributed using Google Forms, with a mandatory response option to avoid missing values. The research instrument was efficiently developed into 20 items, each represented by four indicators adopted from current educational management theories. Respondents' attitudes were measured using a 5-level Likert Scale, with a gradation of answer choices ranging from Score 1 for Strongly Disagree (STS), Score 2 for Disagree (TS), Score 3 for Neutral (N), Score 4 for Agree (S), to Score 5 for Strongly Agree (SS).

Data Analysis Technique

The data analysis in this study employed the Structural Equation Modeling-Partial Least Squares (PLS-SEM) technique. This variance-based approach was chosen because it is considered the most robust and offers a high degree of flexibility in handling complex research models with multiple mediation paths in a relatively small sample size ($n = 51$).

without requiring strict assumptions of data normality. The data analysis phase involved two levels of evaluation: Measurement Model Evaluation and Structural Model Evaluation.

Measurement Model Evaluation (Outer Model): This was conducted to test the validity and reliability of the research instrument. Parameters used included Convergent Validity through the Outer Loading value (threshold ≥ 0.60 to 0.70) and the Average Variance Extracted value ($AVE > 0.50$). Discriminant Validity was evaluated using the Heterotrait-Monotrait Ratio ($HTMT < 0.90$). Meanwhile, reliability testing is measured using Cronbach's Alpha and Composite Reliability (CR) indicators, which are required to be > 0.70 .

Structural Model Evaluation (Inner Model): Conducted to test hypotheses of causal relationships and mediation roles. This test uses the Bootstrapping method with 5,000 subsamples to produce stable statistical parameter estimates for small samples. The decision to test the hypothesis (direct or indirect effect) is based on a T-Statistic value > 1.96 and a significance level of P-Value < 0.05 at the 95% confidence level. Furthermore, the model's predictive power is evaluated through its Coefficient of Determination (R^2).

RESULTS

Measurement Model Evaluation Results (Outer Model)

Measurement model testing was conducted to ensure that all indicators met validity and reliability criteria before testing the structural hypothesis. Convergent validity parameters were assessed based on factor loadings (outer loadings) and Average Variance Extracted (AVE). The PLS-SEM algorithm calculation results showed that the factor loading values for all indicators in each variable were above the tolerance threshold for appropriateness for small samples, ranging from 0.612 to 0.845. The AVE value for the Digital Learning Ecosystem Maturity (X1) variable was 0.534; Teacher Cognitive Agility (X2) was 0.552; Adaptive Instructional Capacity (Y1) was 0.511; Instructional Implementation Effectiveness (Y2) was 0.568; and 21st Century Learning Performance (Z) was 0.615. Because all AVE values were above 0.50, the model was declared to meet the requirements for strong convergent validity. The instrument reliability test was evaluated using Cronbach's Alpha and Composite Reliability (CR) parameters. The test results showed that the Cronbach's Alpha value for all variables was above 0.70, with a value range of 0.739 to 0.821. In line with this, the Composite Reliability value also showed excellent internal consistency because it was above the threshold of 0.70, with the highest variable achievement in 21st Century Learning Performance (0.865) and the lowest in Adaptive Instructional Capacity (0.804). Discriminant validity testing using the Heterotrait-Monotrait Ratio (HTMT) criteria also showed that all inter-construct correlation values were below 0.90. Based on the results of the outer model evaluation, it can be concluded that all research instruments distributed to 51 elementary school teacher respondents in Serang District were declared valid, reliable, and suitable for further analysis.

Results of Structural Model Evaluation (Inner Model) and Hypothesis Testing

A structural model evaluation was conducted to determine the model's predictive power and verify the direction of the proposed causal relationship. Based on the results of the coefficient of determination (R^2) test, the R-square value for the 21st-Century Learning Performance (Z) variable was found to be 0.642. This figure indicates that variations in 21st-Century learning performance among elementary school teachers in Serang District can be explained by the simultaneous contributions of digital ecosystem maturity, teacher cognitive agility, adaptive instructional capacity, and effective learning implementation, amounting to 64.2%. Meanwhile, the remaining 35.8% is influenced by factors outside this model, such as the principal's instructional leadership or teacher intrinsic motivation.

Hypothesis testing was conducted through a bootstrapping procedure with 5,000 subsamples to determine the T-statistics and P-values for direct and indirect effects. The estimated results for the direct effect are summarized in the following table 1:

Table 1. The estimated results for the direct effect

Direct Influence Path	Path Coefficient	T-Statistics	P-Values	Status
X1 → Z	0,245	2,341	0,020	Significant
X2 → Z	0,312	2,984	0,003	Significant
X1 → Y1	0,389	3,712	0,000	Significant
X2 → Y2	0,418	4,105	0,000	Significant
Y1 → Z	0,287	2,654	0,008	Significant
Y2 → Z	0,335	3,118	0,002	Significant

Furthermore, the double-mediating mechanism testing was evaluated through the Specific Indirect Effects value. The calculation results showed two significant mediation paths. First, the $X \rightarrow Y1 \rightarrow Z$ path has a T-statistics value of 2.415 and a P-value of 0.016 (<0.05), which means that Adaptive Instructional Capacity is proven to significantly mediate the influence of the digital ecosystem on 21st-century learning performance. Second, the $X2 \rightarrow Y2 \rightarrow Z$ path produces a T-statistics value of 2.871 and a P-value of 0.004 (<0.05), which proves that Instructional Implementation Effectiveness plays a strong role as a mediator of the relationship between teacher cognitive agility and 21st-century learning performance.

DISCUSSION

The Contribution of Digital Ecosystems and Teacher Cognitive Skills to 21st Century Learning Performance

The findings of this study empirically demonstrate that a mature digital learning ecosystem has a significant direct positive contribution to strengthening the 21st-century learning performance of elementary school teachers in Serang City. Elementary schools supported by a well-established digital superstructure, including device availability, smooth internet access, school policies, and an inclusive digital literacy culture, provide teachers with greater latitude to implement modern teaching models. The availability of integrated learning platforms facilitates the design of collaborative assignments and interactive student communication. These results support the digital education ecosystem management theory, which states that technology will function optimally as an instrument of pedagogical transformation when supported by the systemic readiness of the school's organizational environment (Nguyen & Tuamsuk, 2022).

Furthermore, teacher cognitive agility was found to have the most dominant direct influence on 21st-century learning performance compared to other exogenous variables. Educator cognitive flexibility is a vital internal determinant at the elementary school level. Mentally agile teachers are able to quickly shift teaching strategies from text-based memorization to concrete problem-solving activities that require critical thinking. This cognitive flexibility also makes teachers more adaptive and creative in overcoming limited classroom learning resources, thus achieving optimal 21st-century instructional performance. This finding aligns with the cognitive psychology concept of the teaching profession, which states that teacher mental agility is the primary foundation for pedagogical innovation and efficiency in the era of disruption (Paul et al., 2020).

The Mediating Role of Adaptive Instructional Capacity and Implementation Effectiveness

The main focus and novelty of this research lies in testing the dual mediation pathway. Statistical findings prove that Adaptive Instructional Capacity successfully mediates the influence of digital ecosystem maturity on 21st-century learning performance. This mediation relationship indicates a type of partial mediation, meaning the availability of advanced technology in elementary schools in Serang City does not automatically produce critical thinking outcomes or student creativity, but must first be converted into teacher adaptive capacity in the classroom. A mature digital ecosystem provides teachers with an abundance of data, media, and operational tools; competent teachers will utilize this convenience to differentiate teaching, map the diversity of student learning styles, and develop precise learning aids (scaffolding). This adaptive capacity then stimulates the improvement of 21st-century skills in students (Rustiyana, 2025).

Furthermore, the mediating role of Instructional Implementation Effectiveness has also proven significant in linking teachers' cognitive agility with 21st-century learning performance. The cognitive agility possessed by elementary school teachers in Serang District manifests itself in the form of sequential, structured, timely, yet dynamic learning execution in the classroom. When teachers are able to manage the class efficiently and maintain high student engagement, distortions in the learning environment can be reduced. The results of this effective implementation ultimately create a classroom climate that stimulates students' courage in communicating ideas and collaborating in groups. Thus, the effectiveness of learning implementation acts as an absolute operational bridge that translates teachers' thinking agility into the achievement of real 21st-century competencies in students (Judijanto et al., 2025).

CONCLUSION

Conclusion

This study successfully proved and confirmed the causal model of strengthening 21st-century learning performance in Elementary School teachers in Serang District, Serang City, through the PLS-SEM test structure. The results of the data analysis concluded that the maturity of the digital learning ecosystem and teachers' cognitive agility have a significant direct positive influence on the achievement of 21st-century learning performance. Between the two, teachers' cognitive agility plays the most dominant role in driving the quality of modern learning outcomes at the elementary level. Furthermore, the novelty of this study is proven by the significance of the dual mediation mechanism. Adaptive instructional capacity is proven to be a successful bridge that translates the maturity of the school's digital ecosystem into critical and creative student learning performance. In line with this, the effectiveness of classroom learning implementation is also proven to be a crucial intermediary variable in channeling teachers' mental agility (cognitive agility) towards the realization of a collaborative and communicative 21st-century classroom climate. Accumulatively, the model developed in this study has strong predictive power, where the combination of all variables is able to explain the diversity of variations in strengthening teachers' 21st-century learning performance by 64.2%.

Research Limitations

This study has several limitations that need to be considered in interpreting the results. First, the relatively small sample size, limited to 51 elementary school teacher respondents in one sub-district, requires caution when generalizing the results to a broader scale (such as the provincial or national level). Second, the data collection technique relied entirely on digital self-assessment questionnaires, which opens up the possibility of

subjectivity bias, where respondents tend to provide idealized answers (social desirability bias) compared to actual conditions in the field. Third, this model only captures 64.2% of the variance contribution, leaving 35.8% of other factors influencing 21st-century learning performance unexplored in this study.

Suggestions and Directions for Future Research

Based on the findings and limitations above, several strategic suggestions are recommended. First, the Serang City Education and Culture Office needs to design a teacher training program that focuses not only on technical digital literacy but also on psychological capital aspects such as improving cognitive agility and adaptive teaching capacity (learning differentiation) so that digital infrastructure investments in schools can be optimally converted into competitive graduate quality. Second, elementary school principals in Serang District are expected to continue to mature the digital ecosystem by developing clear SOPs regarding technology integration in the curriculum and promoting a culture of collaboration among teachers through internal school Teacher Working Groups (KKG) to hone collective pedagogical agility. Third, for further research, it is recommended to expand the research locus and increase the sample size to strengthen the data representation. Furthermore, it is recommended to integrate qualitative methods (such as classroom observations or in-depth interviews) to confirm the validity of the questionnaire data, as well as considering other relevant independent variables such as the principal's instructional leadership or students' initial digital literacy levels.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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