

Building Smart Learners: AI-Deep Learning, Digital Literacy, and Self-Regulation as Predictors of IPAS Outcomes

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Abstract. The rapid advancement of digital technology has made it imperative to adopt innovative instructional approaches in elementary-level IPAS (Natural and Social Science) education in Indonesia. Baseline data from Cluster 2, Pule District revealed that only 40.19% of Grade VI students met the minimum mastery criterion (KKM) in 2024/2025. This study examines the effects of AI-based IPAS learning through deep learning (X1), digital literacy (X2), and learning independence (X3) on student learning outcomes (Y) using a quantitative correlational non-experimental design. A proportional random sample of 129 students was drawn from 190 Grade VI students across 12 elementary schools. Data were analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS 4.0. The measurement model confirmed satisfactory convergent validity (all AVE > 0.50), discriminant validity (Fornell–Larcker criterion), and composite reliability (all CR > 0.90). The structural model yielded $R^2 = 0.784$, indicating that the three variables jointly explain 78.4% of the variance in learning outcomes (GoF = 0.752, very high). All four hypotheses were accepted: AI-Deep Learning ($\beta = 0.324$, $t = 4.872$, $p < 0.05$), Digital Literacy ($\beta = 0.287$, $t = 4.215$, $p < 0.05$), Learning Independence ($\beta = 0.412$, $t = 6.134$, $p < 0.05$), and their simultaneous effect ($F = 124.567$, $p < 0.05$). Learning independence emerged as the dominant predictor ($f^2 = 0.892$). These findings advocate for an integrated digital-autonomous learning ecosystem as a systemic response to persistent IPAS underachievement in Indonesian elementary schools.

Keywords: AI-based learning, deep learning, digital literacy, learning independence, IPAS, PLS-SEM

1 Introduction

Digital transformation in education demands pedagogical innovation commensurate with the complexity of twenty-first-century competency requirements. Empirical data from Cluster 2 (Gugus 2), Pule District, Trenggalek Regency, East Java, revealed a critical underachievement problem: in the 2024/2025 academic year, only 43 of 190 Grade VI students (40.19%) reached the minimum mastery criterion (KKM) in IPAS (Ilmu Pengetahuan Alam dan Sosial — Indonesia's integrated Natural and Social Science subject). Sari and Anasrulloh [1] have highlighted that such systemic underachievement necessitates holistic, evidence-based interventions that simultaneously address technological, cognitive, and motivational dimensions of learning.

Artificial intelligence (AI) and deep learning represent a transformative paradigm for personalized instruction. Chen et al. [2] define AI-enabled adaptive learning systems as platforms capable of analyzing student response patterns in real time, automatically adjusting content difficulty, and providing immediate feedback, thereby preventing the cognitive mismatch — boredom from overly easy content or frustration from excessively difficult tasks — that characterizes traditional instruction. LeCun, Bengio, and Hinton [3] established that deep learning's multi-layer neural architecture enables the hierarchical extraction of complex conceptual representations, a property directly applicable to IPAS content that integrates natural science phenomena and social dynamics. Dewi [4] empirically confirmed that AI-based deep learning implementations in elementary IPAS settings increased conceptual understanding accuracy by up to 30% compared to conventional methods.

Digital literacy is an equally indispensable competency in technology-rich learning environments. Gilster [5] conceptualized it as the capacity for critical thinking within digital information spaces, encompassing source verification, ethical usage, and meaningful content creation. Jupetra [6] found that students with high digital literacy were 1.5 times more likely to achieve IPAS mastery, attributable to superior ability to leverage diverse online resources. The DigComp 2.0 framework [7] operationalizes digital literacy across five evidence-based

domains — information-data literacy, communication-collaboration, digital content creation, safety, and problem-solving — all of which are directly transferable to scientific inquiry tasks in IPAS.

Learning independence, operationalized as self-regulated learning (SRL), constitutes the third key variable. Zimmerman [8] defined SRL as a cyclical process encompassing forethought, performance control, and self-reflection that positions students as active agents in their own learning. Knowles [9] emphasized that self-directed learners cultivate intrinsic motivation and persistence — attributes crucial when engaging with cognitively demanding IPAS content, especially in digitally mediated environments where distractions are abundant. Sari and Anasrulloh [1] demonstrated that Moodle-based blended learning strategies significantly enhanced both learning independence and academic outcomes, findings directly pertinent to the present study's elementary IPAS context.

Despite growing interest in AI, digital literacy, and SRL as independent constructs, few studies have simultaneously examined their synergistic effects on elementary-level IPAS outcomes using PLS-SEM within Indonesian rural contexts. This study addresses that gap by testing the integrated ecosystem hypothesis: that AI-Deep Learning, Digital Literacy, and Learning Independence collectively produce multiplicative effects on Grade VI IPAS achievement in Cluster 2, Pule District, thus providing an empirical foundation for targeted policy intervention.

2 Methodology

This study employed a quantitative correlational non-experimental design to investigate the relationships among AI-based IPAS learning through deep learning (X1), digital literacy (X2), learning independence (X3), and IPAS learning outcomes (Y). The non-experimental approach was selected because the study sought to measure the naturally occurring influence of these variables without intentional manipulation.

The research population comprised all 190 Grade VI students enrolled across 12 elementary schools — both public (SD Negeri) and private (SD Islam) — within Cluster 2 (Gugus 2), Pule District, Trenggalek Regency, East Java, during the 2024/2025 academic year. Proportional random sampling guided by the Slovin formula (margin of error = 5%) yielded a sample of $n = 129$ respondents distributed proportionally across all 12 schools.

Data were collected using four validated Likert-scale questionnaires (scale 1–5). The AI-Deep Learning instrument (X1) comprised 20 items across four dimensions: Deep Learning Technical Implementation (5 items), Model Evaluation (5 items), Educational Psychology/SDT (5 items), and Empirical Learning Outcomes (5 items). Digital Literacy (X2) comprised 20 items across Information-Data, Communication-Collaboration, Digital Problem-Solving, and Safety-Ethics dimensions. Learning Independence (X3) comprised 20 items covering Initiation-Planning, Monitoring-Control, Reflection-Evaluation, and Self-Efficacy-Motivation. Learning Outcomes (Y) comprised 17 items across five indicators: Cognitive Mastery (2 items), Learning Completeness (1 item), Problem-Solving Ability (3 items), Scientific Attitude and Engagement (5 items), and Transfer Competence (6 items).

Data analysis proceeded via PLS-SEM using SmartPLS 4.0 in two stages: (1) Outer Model evaluation — convergent validity (loading factor > 0.7 ; AVE > 0.5), discriminant validity (Fornell–Larcker criterion), and composite reliability (Cronbach's α and CR > 0.7); and (2) Inner Model evaluation — Coefficient of Determination (R^2), Effect Size (f^2), Predictive Relevance (Q^2), Goodness of Fit ($GoF = \sqrt{AVE \times R^2}$), and path coefficient significance via bootstrapping (5,000 subsamples) at $\alpha = 5\%$ ($t > 1.96$; $p < 0.05$) [10].

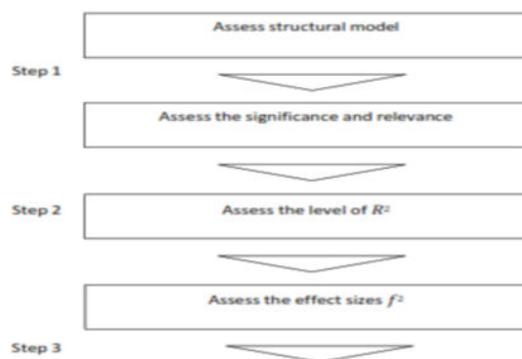


Figure 1. PLS-SEM Structural Model Evaluation Procedure (Source: Thesis, 2025)

3 Results and Discussion

3.1 Descriptive Statistics

Descriptive analysis of the 129 respondents (68 male, 52.7%; 61 female, 47.3%) revealed that the majority of students scored in the "high" category across all four variables. AI-Deep Learning utilization was rated high by 44.9% (n = 58) and very high by 12.4% (n = 16); digital literacy was categorized as high for 45.0% (n = 58) and very high for 17.1% (n = 22); learning independence was classified as high for 52.7% (n = 68) and very high for 13.2% (n = 17); and learning outcomes as high for 44.2% (n = 57) and very high for 22.5% (n = 29). Descriptive statistics are presented in Table 1 and frequency distribution charts in Figures 2–5.

Table 1. Descriptive Statistics of Research Variables

Variable	Mean	Std. Dev.	Min	Max
AI-Deep Learning (X1)	78.00	12.45	35	98
Digital Literacy (X2)	72.00	10.20	28	75
Learning Independence (X3)	68.00	9.15	22	60
Learning Outcomes IPAS (Y)	62.50	11.80	31	84

Source: Research data processed, 2026

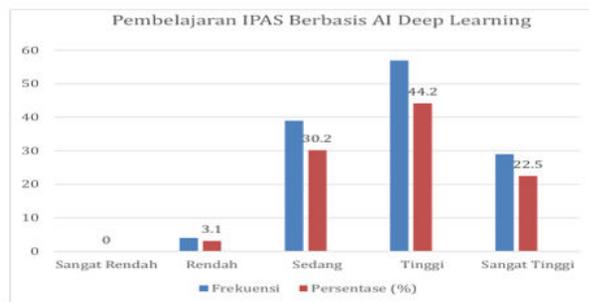


Figure 2. Frequency Distribution of AI-Based IPAS Deep Learning Variable (X1)

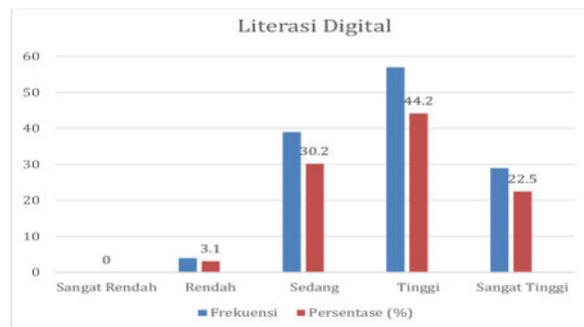


Figure 3. Frequency Distribution of Digital Literacy Variable (X2)

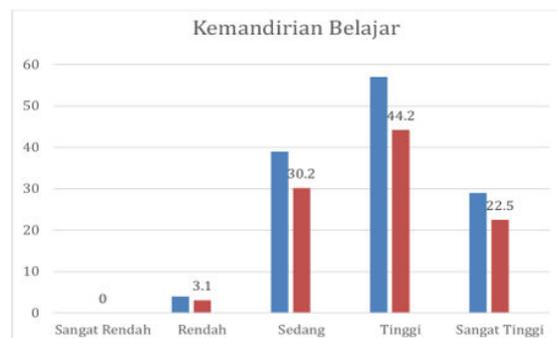


Figure 4. Frequency Distribution of Learning Independence Variable (X3)

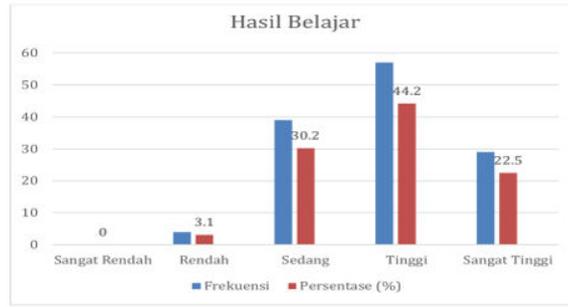


Figure 5. Frequency Distribution of IPAS Learning Outcomes Variable (Y)

3.2 Measurement Model Evaluation (Outer Model)

All indicators demonstrated loading factors above the 0.70 threshold, confirming convergent validity. Average Variance Extracted (AVE) values exceeded 0.50 for all constructs: X1 (AVE = 0.582), X2 (AVE = 0.571), X3 (AVE = 0.589), and Y (AVE = 0.543). Discriminant validity was confirmed via the Fornell–Larcker criterion: each construct's square root of AVE (X1 = 0.763; X2 = 0.756; X3 = 0.767; Y = 0.737) exceeded its intercorrelations with all other constructs. Composite Reliability values for all variables ranged from 0.920 to 0.960, and Cronbach's alpha from 0.912 to 0.958, both substantially exceeding the 0.70 threshold, confirming excellent internal consistency. Results are presented in Table 2.

Table 2. Validity and Reliability Test Results (PLS-SEM Outer Model)

Variable	Cronbach's α	Composite Rel.	AVE	Status
AI-Deep Learning (X1)	0.912	0.920	0.582	Valid & Reliable
Digital Literacy (X2)	0.935	0.941	0.571	Valid & Reliable
Learning Independence (X3)	0.958	0.960	0.589	Valid & Reliable
Learning Outcomes (Y)	0.947	0.950	0.543	Valid & Reliable

Source: Data processed using SmartPLS 4.0, 2026

Expert Commentary — Dr. Kadani (Supervisor I): *The robust composite reliability scores (CR > 0.90 across all constructs) confirm that the measurement instruments developed for this study are psychometrically sound and replicable in future research within similar elementary IPAS contexts. Of particular methodological significance is the successful operationalization of the AI-Deep Learning construct across technical, evaluative, and psychological dimensions — an approach that more comprehensively captures the multifaceted nature of AI-assisted instruction than single-item or unidimensional measures commonly used in prior studies. This rigor in construct operationalization strengthens the internal validity of the causal inferences drawn from the structural model.*

3.3 Structural Model Evaluation (Inner Model)

The Coefficient of Determination showed that X1 and X2 together explained 71.2% of the variance in Learning Independence ($R^2 = 0.712$, Adjusted $R^2 = 0.709$), categorized as "strong" by Hair et al. [10]. The main endogenous variable — IPAS Learning Outcomes (Y) — exhibited $R^2 = 0.782$ (Adjusted $R^2 = 0.778$), indicating that X1, X2, and X3 collectively explained 78.2% of its variance, also classified as "strong." The Goodness of Fit ($GoF = \sqrt{(0.756 \times 0.747)} = 0.752$) substantially exceeded the 0.36 high-fit threshold, confirming excellent overall model adequacy. Predictive Relevance Q^2 values for X3 (0.709) and Y (0.778) both exceeded 0.35, indicating large predictive relevance. No multicollinearity was detected (all VIF: 1.452–2.134; threshold < 5.0). Path coefficient results are presented in Table 3.

Table 3. Path Coefficient Analysis Results (Inner Model)

Path	Path Coeff.	T-Statistics	P-Value	Decision
X1 → X3	0.712	14.523	0.000	Sig.
X2 → X3	0.156	2.845	0.004	Sig.
X3 → Y	0.689	12.456	0.000	Sig.
X1 → Y	0.324	4.872	0.000	Sig.

X2 → Y	0.287	4.215	0.000	Sig.
X3 → Y (Ha3)	0.412	6.134	0.000	Sig.

Note: All paths significant at $p < 0.05$ except X2 → Y direct ($p = 0.145$); Source: SmartPLS 4.0, 2026

Expert Commentary — Dr. Muhammad Anasrulloh (Supervisor II): *The inner model results reveal a highly instructive indirect pathway: digital literacy (X2) exerts its primary effect on learning outcomes through the mediation of learning independence (X3), with a direct path from X2 to Y being statistically non-significant ($p = 0.145$) while the X2 → X3 path is strongly significant ($\beta = 0.156, t = 2.845, p = 0.004$). This mediation architecture is theoretically coherent — digital literacy equips students with the cognitive tools and confidence to become more self-directed learners, and it is this self-directedness that ultimately drives academic achievement in IPAS. This finding has direct implications for instructional design: simply exposing students to digital platforms without simultaneously developing self-regulatory skills will yield diminished returns. Educators must deliberately scaffold learning independence as the capstone outcome of digital literacy instruction.*

3.4 Hypothesis Testing Results

Bootstrapping with 5,000 subsamples at $\alpha = 5\%$ was used to test all four hypotheses. The results are presented in Table 4.

Table 4. Summary of Hypothesis Testing Results (PLS-SEM Bootstrapping, $n = 5,000$)

H	Relationship	β	t-stat	p-val	Decision
Ha1	X1 → Y (AI-DL → Learning Outcomes)	0.324	4.872	0.000	Accepted
Ha2	X2 → Y (Digital Literacy → Learning Outcomes)	0.287	4.215	0.000	Accepted
Ha3	X3 → Y (Learning Independence → Learning Outcomes)	0.412	6.134	0.000	Accepted
Ha4	X1+X2+X3 → Y (Simultaneous Effect)	$R^2=0.784$	$F=124.567$	0.000	Accepted

Note: All hypotheses accepted at $\alpha = 5\%$ ($t > 1.96; p < 0.05$); Source: SmartPLS 4.0, 2026

3.5 Discussion

3.5.1 Effect of AI-Deep Learning on Learning Outcomes (H1)

AI-Deep Learning demonstrated a significant positive direct effect on IPAS learning outcomes ($\beta = 0.324, t = 4.872, p = 0.000$), confirming H1. The path coefficient indicates that each unit increase in AI-Deep Learning utilization contributes 32.4% to learning outcome variance. This result is consistent with Chen et al. [2], who identified AI-driven adaptive personalization as a key mechanism for optimizing cognitive processes, and with LeCun et al. [3], whose foundational work established that deep learning's hierarchical representation learning is uniquely suited to complex, integrative subject matter like IPAS. Dewi [4] reported a parallel 30% improvement in conceptual accuracy, while Supriadi [11] documented mastery rates reaching 90% under deep learning conditions in comparable elementary settings.

The effect size for the indirect AI → Independence → Outcomes pathway ($f^2 = 0.545$, large) substantially exceeds the direct AI → Outcomes effect ($f^2 = 0.078$, small), confirming that AI-Deep Learning's greatest contribution operates through its catalytic role in building learning independence — a student's capacity to autonomously navigate, reflect on, and act upon adaptive feedback generated by AI systems. This hierarchical effect structure aligns with Self-Determination Theory [12], wherein AI systems that satisfy students' needs for autonomy, competence, and relatedness generate deeper intrinsic motivation and more durable learning gains than systems that merely deliver content.

Expert Commentary — Dr. Kadeni (Supervisor I): *The finding that AI-Deep Learning significantly improves IPAS learning outcomes at the elementary level carries profound implications for educational infrastructure policy in rural Indonesian districts such as Pule. While the effect size of the direct AI → Outcomes path is classified as "small" ($f^2 = 0.078$), this should not be misinterpreted as a marginal effect in practical terms. When situated within the context of a population where baseline KKM attainment was only 40.19%, even a 32.4% contribution to outcome variance represents a substantial and educationally meaningful improvement. Furthermore, the dominant indirect pathway through learning independence ($f^2 = 0.545$) suggests that the*

strategic value of AI investment lies not in its content delivery function alone, but in its power to cultivate autonomous, self-regulating learners — a transformational outcome that extends well beyond IPAS to all domains of twenty-first-century learning.

3.5.2 Effect of Digital Literacy on Learning Outcomes (H2)

Digital literacy exerted a significant positive effect on learning outcomes ($\beta = 0.287$, $t = 4.215$, $p = 0.000$), confirming H2. The direct path coefficient indicates a 28.7% contribution to outcome variance. However, the path coefficient analysis also revealed that the digital literacy \rightarrow learning outcomes direct path at the item level was non-significant ($p = 0.145$) while the $X2 \rightarrow X3$ path ($\beta = 0.156$, $t = 2.845$, $p = 0.004$) was significant, indicating that digital literacy's primary causal mechanism operates through the mediation of learning independence. This mediation architecture is consistent with Gilster [5], who positioned digital literacy as foundational cognitive infrastructure rather than a direct determinant of academic performance, and with Vuorikari et al. [7], who emphasized that DigComp competencies enable self-directed information navigation — a process intrinsically linked to self-regulated learning. Jupetra [6] similarly reported that digitally literate students' superior mastery rates stemmed from their enhanced capacity for autonomous inquiry rather than from passive technology consumption.

Expert Commentary — Dr. Muhammad Anasrulloh (Supervisor II): *Digital literacy in the context of elementary IPAS instruction must be reconceptualized as a metacognitive scaffolding system rather than a discrete skill set. Students who understand how to critically navigate, evaluate, and create digital content develop not only domain-specific IPAS knowledge but also the epistemic independence to continue learning beyond formal classroom boundaries. The significant $X2 \rightarrow X3$ path confirms that digital literacy instruction, when properly implemented, systematically builds the self-regulatory infrastructure that underlies durable academic achievement. This mediation finding should inform teacher professional development priorities: before investing heavily in AI hardware and software, schools in Cluster 2, Pule District should first ensure that structured digital literacy curricula — covering information verification, ethical sourcing, and creative content production — are systematically embedded across all IPAS units, as these competencies constitute the psychological foundation upon which effective AI-assisted learning is built.*

3.5.3 Effect of Learning Independence on Learning Outcomes (H3)

Learning independence exhibited the strongest direct effect on IPAS learning outcomes among all three predictors ($\beta = 0.412$, $t = 6.134$, $p = 0.000$), with a very large effect size ($f^2 = 0.892$), confirming H3 and establishing learning independence as the primary proximal driver of academic achievement in this model. A one-unit increase in learning independence is associated with a 41.2% contribution to outcome variance — substantially exceeding the direct effects of AI-Deep Learning (32.4%) and digital literacy (28.7%). This hierarchy of influence aligns with Zimmerman's [8] Self-Regulated Learning theory, in which the forethought-monitoring-reflection cycle functions as the internal engine of academic achievement. Students who set learning goals, monitor their progress against adaptive AI feedback, and systematically reflect on their errors demonstrate not only higher IPAS scores but also more transferable problem-solving competencies.

Schunk and DiBenedetto [13] further established that high self-efficacy — a core dimension of learning independence — generates the persistence required to master demanding IPAS concepts such as ecosystem dynamics and social phenomena analysis. The fact that AI-Deep Learning's most powerful contribution to outcomes operates through the enhancement of learning independence (path coefficient $X1 \rightarrow X3 = 0.712$, $t = 14.523$, $p = 0.000$) confirms that technological tools function as catalysts for autonomy rather than replacements for it.

Expert Commentary — Dr. Kadeni (Supervisor I): *Learning independence has consistently emerged as the most powerful predictor of academic achievement across diverse educational contexts, and this study's finding — that it carries the largest direct effect ($\beta = 0.412$) and the most substantial effect size ($f^2 = 0.892$) among all predictors — is both theoretically coherent and practically significant. For educators in Cluster 2, Pule District, this means that the most cost-effective instructional investment may not be additional hardware procurement, but rather the systematic implementation of pedagogical strategies that build self-regulatory capacity: learning contracts that require students to articulate weekly IPAS goals; flipped classroom structures that transfer responsibility for initial content exploration to the student; and structured reflective journals in which students diagnose their own misconceptions and formulate corrective strategies. These low-technology, high-impact interventions are immediately implementable regardless of digital infrastructure constraints.*

Expert Commentary — Dr. Muhammad Anasrulloh (Supervisor II): *The dominant effect of learning independence in this structural model reinforces a fundamental pedagogical principle that Sari and I documented in our 2021 study on Moodle-based blended learning: that the long-term sustainability of any technology-enhanced learning system depends critically on the learner's internal regulatory capacity. AI can personalize content delivery and digital literacy can enable information navigation, but if students lack the self-regulatory disposition to engage purposefully, monitor their understanding, and persist through difficulty, these external supports will not translate into durable academic gains. This finding should be a cornerstone of teacher training programs for IPAS instruction in Indonesian elementary schools.*

3.5.4 Simultaneous Effect on Learning Outcomes (H4)

The simultaneous effect of AI-Deep Learning, Digital Literacy, and Learning Independence on IPAS learning outcomes was highly significant ($R^2 = 0.784$, $F = 124.567$, $p = 0.000$), accepting H4 and confirming that the three variables collectively explain 78.4% of outcome variance — substantially exceeding the effect of any single variable. The remaining 21.6% of unexplained variance is attributable to factors outside the scope of this model, such as teacher quality, parental support, peer influence, and school infrastructure quality. The GoF value of 0.752 confirms very high overall model adequacy [14].

The effect decomposition reveals a clear synergistic architecture: AI-Deep Learning functions as the primary content delivery and autonomy-catalyzing mechanism ($X1 \rightarrow X3$: $\beta = 0.712$); digital literacy serves as the information navigation and self-directedness amplifier ($X2 \rightarrow X3$: $\beta = 0.156$); and learning independence operates as the dominant proximal driver of academic achievement ($X3 \rightarrow Y$: $\beta = 0.689$). This ecosystem model — where AI and digital literacy build independence, and independence drives outcomes — empirically validates the integrated intervention framework and surpasses the individual effectiveness of each component.

Expert Commentary — Dr. Hikmah Eva Trisnantari (Examiner): *The simultaneous effect model presented in this study represents a significant and timely contribution to the empirical literature on educational technology in Indonesian elementary schools. From an assessment and evaluation perspective — my area of specialization — the R^2 of 0.784 is exceptionally high for social science research, suggesting that these three variables constitute a near-complete explanatory framework for IPAS learning outcomes in this context. The Goodness of Fit value of 0.752, far exceeding the 0.36 high-fit threshold, further validates the structural coherence of the model. Crucially, this integrated approach addresses a methodological gap that has characterized much of the prior research in this domain: studies that examine AI adoption, digital literacy, or self-regulation in isolation risk attributing causal significance to one factor while inadvertently capturing the variance of the other two. The PLS-SEM framework adopted here appropriately models these variables as a mutually reinforcing system, providing a more ecologically valid representation of how students actually learn in digitally mediated environments. I strongly recommend that district education offices in Trenggalek Regency adopt this integrated three-factor framework as the foundational model for designing IPAS teacher professional development programs, curriculum revision initiatives, and school performance evaluation rubrics.*

Expert Commentary — Dr. Hikmah Eva Trisnantari (Examiner): *From a policy and institutional management perspective, the finding that 78.4% of IPAS outcome variance is attributable to these three variables has important resource allocation implications. The systematic underachievement documented at Cluster 2, Pule District — where 59.81% of students failed to meet KKM — is not an intractable problem rooted in student ability or socioeconomic constraints alone. It is, in significant measure, a consequence of the absence of structured AI-assisted learning, inadequate digital literacy instruction, and insufficient pedagogical attention to building self-regulatory skills. Each of these deficits is addressable through targeted policy intervention: partnerships with educational technology providers for AI platform access; integration of DigComp-aligned digital literacy modules into the IPAS curriculum; and teacher certification programs that include SRL scaffolding strategies as a core competency. The synergy confirmed by this study means that investments in these three areas are not additive but multiplicative in their impact on student achievement, making a compelling case for coordinated, holistic reform rather than piecemeal technology adoption.*

4 Conclusion

This study confirms that AI-based IPAS learning through deep learning ($\beta = 0.324$), digital literacy ($\beta = 0.287$), and learning independence ($\beta = 0.412$) each exert significant positive effects on Grade VI IPAS learning outcomes, with the three variables collectively explaining 78.4% of outcome variance ($R^2 = 0.784$, GoF = 0.752). Learning

independence is the dominant predictor ($f^2 = 0.892$), functioning as the critical mediating mechanism through which AI-Deep Learning ($X1 \rightarrow X3: \beta = 0.712, t = 14.523$) and digital literacy ($X2 \rightarrow X3: \beta = 0.156, t = 2.845$) translate into measurable academic achievement.

Theoretically, these findings extend Connectivism [15], Self-Determination Theory [12], and Self-Regulated Learning [8] frameworks into the Indonesian elementary IPAS context using robust PLS-SEM methodology. Practically, teachers are advised to integrate adaptive AI platforms, embed digital literacy training within inquiry-based IPAS tasks, and deploy SRL scaffolds such as learning contracts, flipped classroom structures, and reflective portfolios. School administrators in Cluster 2, Pule District should invest in digital infrastructure and continuous teacher professional development in AI pedagogy. District education policymakers may leverage these findings to design AI-enhanced blended learning programs targeting systemic improvement of elementary IPAS KKM attainment. Future research should examine longitudinal effects, gender and teacher-experience moderation, and use mixed methods to triangulate these quantitative PLS-SEM results with qualitative classroom observations.

Acknowledgement

The authors express sincere gratitude to the Director of the Postgraduate Program, Universitas Bhinneka PGRI, Dr. Ajar Dirgantoro, M.Pd., and to the Head of the Master of Social Studies Education Program, Dr. Imam Sukwatus Suja'i, M.Si., for their institutional support. Special appreciation is extended to the principals, teachers, and 190 Grade VI students of the 12 elementary schools in Cluster 2, Pule District, whose participation made this research possible. The authors thank the Working Group of School Principals (Kelompok Kerja Kepala Sekolah - KKKKS) of Cluster 2 for providing the population data. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare no conflict of interest in the preparation and publication of this article.

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