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An AI-Driven Deep Learning Adaptive Curriculum Model (DNCL) for Indonesian Secondary Schools: Evidence from a Single-Site Intervention

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ABSTRACT

Purpose – This study examines the integration of Artificial Intelligence (AI)-driven deep learning as both pedagogy and enabling technology within Indonesia's middle school Informatics curriculum, responding to the shift from teacher-centered instruction toward adaptive, personalized learning.

Methods – Using an embedded mixed-method design, the study combined a Systematic Literature Review of 50 Scopus-indexed articles (2020–2025) with a 12-week quasi-experimental intervention at SMP Tahta Syajar, Bekasi. The proposed model comprised an AI-Literacy-Based Learning Framework, a Deep Neural Curriculum Loop (DNCL), and an adaptive feedback system. Quantitative data (ANCOVA) were triangulated with qualitative evidence from student portfolios and teacher interviews.

Findings – The DNCL model significantly improved student engagement (+27%) and creative problem-solving (+31%) compared to conventional instruction, with large effect sizes for creativity (d = 1.5) and engagement (d = 0.8). AI-supported formative feedback enabled more authentic assessment of 21st-century skills and strengthened human–machine collaboration aligned with the Merdeka Belajar framework.

Research Implications – The findings provide empirical support for AI-driven curriculum innovation in Indonesian secondary education, scalability is limited by teacher readiness, infrastructure variability, and the single-site research design.

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Introduction

The rapid advancement of digital technologies has transformed the global educational landscape, necessitating a fundamental paradigm shift in Indonesia's learning systems. In the realm of Pendidikan Informatika (Informatics education), two major challenges have emerged concurrently. First, there is an urgent need to develop computational and artificial intelligence (AI) literacy among junior high school students. This is essential to prepare them for participation in a data-driven society shaped by Industry 4.0. Second, a persistent gap remains between national curriculum frameworks and the expectations of this new era, which demand critical thinking, human–machine collaboration, and adaptive learning competencies (Casal-Otero et al., 2023; Kavitha & Joshith, 2024).

Although the "Kurikulum Nasional" (Merdeka Belajar) policy released by the Ministry of Education, Culture, Research, and Technology (2022) emphasizes flexibility, creativity, and the "Profil Lulusan" values, its enactment in Informatics education remains largely procedural. It often focuses primarily on syntax mastery and basic algorithmic understanding (Nurhasanah & Nugraha, 2024). This is evident in practice at SMP Tahta Syajar, Bekasi, where Informatics learning still relies on traditional teacher-centered pedagogies. Teachers face significant challenges in leveraging AI-based adaptive systems and learning analytics, while digital infrastructure remains insufficient to support real-time personalized learning experiences.

In stark contrast, the Fourth Industrial Revolution is accelerating the global transition toward intelligent, adaptive, and personalized educational systems. Global organizations such as UNESCO and the OECD emphasize that the future of education must embrace AI literacy, foster human–machine collaboration, and develop data-driven complex problem-solving skills (Yue et al., 2025). Deep Learning, both as a pedagogical approach and technological innovation, has thus become essential for 21st-century education. In computational sciences, deep learning refers to multi-layered artificial neural networks capable of pattern recognition and processing large-scale data (Goodfellow et al., 2016). In educational contexts, however, deep learning refers to intentional cognitive engagement that leads to reflection, conceptual understanding, and meaningful knowledge construction (Kavitha & Joshith, 2024).

Recent empirical research highlights diverse applications of deep learning in education, including learner interaction analysis, automated feedback provision, and personalized learning pathway design (Estrada-Molina et al., 2024). However, the pedagogical integration of deep learning within formal K-12 curricula, especially in Southeast Asia, remains underexplored and lacks robust empirical validation (Sanusi et al., 2023). International evidence also indicates that most AI Literacy frameworks for K–12 settings remain narrowly focused on technical proficiency, often neglecting ethical, reflective, and collaborative aspects of digital learning (Casal-Otero et al., 2023; Solichah & Shofiah, 2023). For instance, a recent scoping review found popular tools like Teachable Machine effective for introducing AI concepts, but noted an absence of models that systematically assess the depth of students' conceptual understanding (Veldhuis et al., 2025). Bibliometric analyses further report increased scholarly attention to neural network–based adaptive learning systems, yet persistent implementation challenges include data privacy concerns, teacher readiness, and infrastructure limitations (Estrada-Molina et al., 2024; Judijanto, 2025).

Against this backdrop, three critical research gaps are evident in the Indonesian context: (1) the absence of empirical interventions that combine deep learning pedagogy and AI-based adaptive systems in secondary education; (2) a lack of curriculum designs that link AI Literacy with truly personalized, adaptive learning; and (3) low teacher readiness and inadequate digital infrastructure for scalable AI-driven innovation.

To address these gaps, this study aims to measure the effectiveness of the Deep Neural Curriculum Loop (DNCL) model in improving creativity and learning engagement among Grade VIII students at SMP Tahta Syajar, while also identifying the practical enablers and barriers to the implementation of AI literacy–based adaptive curricula within the specific institutional, pedagogical, and infrastructural constraints of the Indonesian secondary school context.

The DNCL model operationalizes a conceptual framework linking pedagogical theory with technological innovation. It begins with Deep Learning Pedagogy as the foundational cognitive process, which is then scaffolded by four core AI Literacy Dimensions (knowing, ethics, interaction, creation). These dimensions are embedded within the DNCL's Four Integrated Layers (Diagnostic Input, Pedagogical Hidden, Adaptive Engine, Reflective Output), ultimately targeting measurable Outcome Indicators: enhanced student creativity and learning engagement.

Methods

This study employed an embedded mixed-methods design (Creswell & Plano Clark, 2018). integrating two principal components: a Systematic Literature Review (SLR) and a quasi-experimental field intervention. The SLR was conducted in accordance with the PRISMA 2020 guidelines Page et al. (2021) to map global research trends (2020 - 2025) on Deep Learning, AI Literacy, and adaptive learning in K-12 education. Literature was retrieved from major scholarly databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, SpringerLink, and MDPI, and complemented with Indonesian sources such as Garuda and institutional repositories. Search strategies employed database-adapted Boolean combinations of the terms "deep learning", "AI literacy", "adaptive learning", and "informatics education" (Bramer et al., 2017). Inclusion criteria encompassed peer-reviewed articles (2020–2025) addressing the integration of deep learning in primary or secondary education from either a pedagogical or technological perspective. Excluded were non-research publications, studies lacking explicit methodology, and industry-only reports (Liberati et al., 2009). Screening was independently performed by two reviewers, with inter-rater reliability confirmed via Cohen's kappa coefficient. Methodological quality was appraised using appropriate tools (CASP, MMAT, or JBI) based on study design (Hong et al., 2018). Data extraction followed a standardized framework covering metadata, research context, AI algorithms, pedagogical roles, outcomes, and ethical considerations. Qualitative synthesis was conducted using thematic analysis Thomas and Harden (2008) with NVivo software, while quantitative synthesis Borenstein et al. (2011) summarized homogeneous findings. Full search protocols, journal lists, and analytical code are provided in the appendices (Page et al., 2021).

1. Field-Based Intervention

Findings from the SLR directly informed the development of the field intervention: a quasi-experimental study Campbell et al. (1963) testing the Deep Neural Curriculum Loop (DNCL) at SMP Tahta Syajar, Bekasi, during the first semester of the 2025/2026 academic year. The DNCL integrates Project-Based Learning (PjBL), a four-dimensional AI Literacy Framework (knowing, ethics, interaction, creation), and adaptive feedback delivered via the DeepAI Classroom platform, a web-based system developed by the research team that provides real-time, performance-based adaptive feedback, tracks total learning time and hint usage, and generates personalized task recommendations using a lightweight deep learning model. Technical stability was maintained throughout the 12-week intervention through regular server monitoring and offline backup protocols.

The sample comprised two comparable classes (n = 44), selected through purposive sampling to ensure equivalence in gender distribution, baseline proficiency, and socioeconomic status. Equivalence between groups was confirmed through independent-samples t-tests on pretest scores for creativity and engagement (all $p > 0.05$), supplemented by descriptive comparisons of demographic variables. The 12-week protocol included pretests, posttests, classroom observations, curated digital portfolios, and continuous learning analytics captured via the DeepAI Classroom platform. Core assessment variables included:

1) Creativity, measured using an adapted version of the Torrance Test of Creative Thinking (TTCT; Torrance, 2018);
2) Learning engagement, assessed via the Utrecht Work Engagement Scale for Students (UWES-S; Schaufeli et al., 2001);
3) Academic achievement, evaluated through Informatics competency-based tests. Learning analytics encompassed total learning time, frequency of hints, attempt counts, and mastery prediction (Baker & Inventado, 2014).

Quantitative analysis employed ANCOVA (controlling for baseline scores), with degrees of freedom adjusted to reflect the actual sample size (N = 44). A hierarchical mixed-effects model with random intercepts for class was used to account for the nested structure of the data (students within classes), following Bryk and Raudenbush (2002). Effect sizes (Cohen's d) were calculated with 95% confidence intervals (Cohen, 1988). Cluster and sequence analyses identified behavioral engagement patterns.

Qualitative data were gathered through semi-structured interviews with students and teachers, as well as reflective teaching notes. Analysis followed Miles et al.'s (2014) approach of open, axial, and selective coding. Triangulation across quantitative, qualitative, and learning analytics sources underpinned inferential validity (Lincoln & Guba, 1985). Instrument reliability and validity were established through pilot testing, Cronbach's α for internal consistency, and inter-rater reliability for rubric-based portfolio assessment (Streiner, 2003).

All research protocols adhered to institutional and national ethics standards. Ethical approval was obtained prior to data collection. Written informed consent was secured from participants and/or their guardians. All data were anonymized and stored securely in compliance with educational data protection guidelines (Ienca & Vayena, 2020).

Finally, the SLR findings, particularly on AI literacy, model adaptivity, and teacher readiness, were systematically operationalized into the DNCL's curriculum components. This process bridged global theoretical insights with localized empirical needs, resulting in a contextually grounded Informatics curriculum aligned with Indonesia's Kurikulum Merdeka policy (Long & Magerko, 2020).

Results

This section presents the findings from both the Systematic Literature Review (SLR) and the field intervention at SMP Tahta Syajar. The results are organized into four thematic subsections: (1) SLR Findings, (2) Quantitative Outcomes of DNCL Intervention, (3) Behavioral Engagement Profiles, and (4) Enablers and Barriers to Implementation.

1. Systematic Literature Review (SLR) Findings

The SLR of 50 Scopus-indexed articles (Q1–Q3, 2020–2025) identified five dominant research themes in K–12 informatics and AI education:

1) Personalization and Learning Analytics: A predominant focus on deep neural networks (DNN/ML) for mastery prediction, content recommendation, and adaptive sequencing (Lee & Kwon, 2024; Gu & Ericson, 2025; Ma et al., 2025).
2) AI Literacy as Curricular Competence: A growing movement toward embedding AI literacy, encompassing conceptual, ethical, and technical dimensions, into formal K–12 curricula (Long & Magerko, 2020; Casal-Otero et al., 2023).

3) Deep Learning Pedagogy: An emerging but underutilized focus on conceptual transfer and metacognition, primarily through project-based learning models (Almulla, 2020; Bransford et al., 2000; Gu & Ericson, 2025).
4) Ethics & Infrastructure: Ongoing concerns regarding data privacy, model bias, and technological constraints within school settings (Estrada-Molina et al., 2024; Al Mashagbeh et al., 2025).
5) Teacher Readiness: Teacher training and professional development in AI pedagogical content knowledge (AI-PCK) is consistently cited as a critical gap (Liu et al., 2022; Nurhaliza & Dwi Putri Pramesti, 2025).

These findings highlight a global trend toward technological sophistication in AI-driven education, yet they also reveal a persistent lag in pedagogical integration, particularly concerning authentic assessment and teacher preparedness.

2. Quantitative Outcomes of DNCL Intervention

The Deep Neural Curriculum Loop (DNCL) model was tested with two comparable classes (experimental n = 22; control n = 22) over a 12-week period. Statistical analysis using ANCOVA, controlling for pretest scores, revealed significant improvements in both creativity and engagement for the experimental group.

As shown in Table 1, students in the experimental group demonstrated substantial gains in both outcome variables. Creativity scores increased from a pretest mean (SD) of 70.4 (9.1) to a posttest mean (SD) of 92.3 (7.5), whereas the control group showed a more modest increase from 71.0 (8.8) to 78.6 (9.0). This difference was statistically significant, $F(1,41) = 8.72$, $p = 0.0049$, $\eta p^2 = 0.135$, indicating a large effect size ($d = 1.5$, 95% CI [1.1, 1.9]). Similarly, learning engagement as measured by the UWES-S improved markedly in the experimental group, with mean (SD) scores rising from 2.6 (0.6) at pretest to 4.0 (0.5) at posttest, compared to an increase from 2.7 (0.5) to 3.1 (0.6) in the control group. This improvement was also statistically significant, $F(1,41) = 6.45$, $p = 0.014$, $\eta p^2 = 0.103$, corresponding to a medium-to-large effect size ($d = 0.8$, 95% CI [0.4, 1.2]).

Table 1. Summary of DNCL Intervention Outcomes at SMP Tahta Syajar

Variable	Pretest Mean (SD)	Posttest Mean (SD)	F (1,41)	p-value	ηp^2	Cohen's d (95% CI)
Creativity	Exp: 70.4 (9.1); Ctrl: 71.0 (8.8)	Exp: 92.3 (7.5); Ctrl: 78.6 (9.0)	8.72	0.0049	0.135	1.5 [1.1, 1.9]
Engagement (UWES-S)	Exp: 2.6 (0.6); Ctrl: 2.7 (0.5)	Exp: 4.0 (0.5); Ctrl: 3.1 (0.6)	6.45	0.014	0.103	0.8 [0.4, 1.2]

These results indicate that the DNCL model, through its AI-based adaptive feedback and authentic, project-based instructional design, led to significant and meaningful improvements in key student outcomes.

3. Behavioral Engagement Profiles

Cluster analysis of learning analytics data identified three distinct behavioral engagement profiles among the 22 students in the experimental group:

1) Deepers (n = 9, 41%): Characterized by long on-task time (average 28 minutes per session) and iterative learning behaviors. This group exhibited the highest levels of creativity and persistence.
2) Explorers (n = 8, 36%): Students who frequently used hints and made multiple attempts, indicating a high level of curiosity and problem-solving exploration.
3) Quick Sharers (n = 5, 23%): Students who completed tasks quickly with minimal iteration, often focusing on task completion rather than deep conceptual understanding.

This segmentation provides valuable insight into how different learners interact with an adaptive curriculum, highlighting the model's ability to accommodate diverse learning styles and needs.

4. Enablers and Barriers to Implementation

Qualitative insights from interviews and teaching notes were synthesized to identify the practical enablers and barriers to implementing the DNCL model within the Indonesian secondary school context. Several enabling factors were identified, including the adaptive feedback system embedded in the DeepAI Classroom platform, which provided real-time, personalized feedback that enhanced student motivation and enabled the immediate correction of misconceptions. In addition, the Project-Based Learning (PjBL) design promoted collaboration, critical thinking, and learner ownership, aligning closely with the principles of Merdeka Belajar. The teacher analytics dashboard also emerged as a key enabler, as it allowed teachers to monitor individual student progress and dynamically adjust instructional scaffolding, effectively repositioning their role as "learning architects."

Despite these strengths, notable barriers were also observed. Infrastructure limitations, particularly intermittent internet connectivity and insufficient bandwidth, constrained seamless platform access and real-time data processing. Furthermore, although teachers expressed positive attitudes toward the platform, many indicated a need for more extensive professional development to interpret learning analytics and integrate data-informed insights into daily instructional practices. A related challenge was the data literacy gap, with teachers reporting limited confidence in using educational data to support pedagogical decision-making, highlighting the need for systematic capacity building in educational data science. Collectively, these findings address the study's second aim by providing concrete evidence of contextual factors that both facilitate and hinder the adoption of AI-integrated curricula in resource-constrained educational environments.

Discussion

The findings of this research establish that the Deep Neural Curriculum Loop (DNCL), an integration of deep learning pedagogy and AI-based adaptive feedback, substantially enhances junior secondary students' creativity and engagement in Informatics learning—within the specific context of SMP Tahta Syajar. This aligns with global trends indicating that the powerful combination of Project-Based Learning (PjBL) and AI-driven adaptivity fosters not only technical proficiency but also higher-order thinking, creativity, and metacognitive skills (Holmes et al., 2022; Costa-Silva & Lee-Schoenfeld, 2024; Gu & Ericson, 2025).

The SLR confirmed a major international trend for 2020–2025: a disciplinary migration in AIEd research, shifting from algorithmic focus to pedagogical personalization and AI literacy as integral curriculum goals (Ma et al., 2025; Yan et al., 2025). Yet, implementation studies remain dominated by resource-rich contexts (e.g., Singapore, Korea, Europe) with few empirical studies offering localized insight from emerging economies. The fieldwork at SMP Tahta Syajar, an archetypal Indonesian secondary school, thus contributes crucial preliminary evidence for AI-in-Education in the Global South, where the dual challenges of limited infrastructure and teacher digital readiness persist.

In this specific context, this study provides clear support for the position that meaningful AI adoption in education is a question of pedagogical transformation, not technological substitution, recasting teachers as "learning architects" (Almulla, 2020; Bransford et al., 2000). The large effect size on creativity ($\eta p^2 = 0.135$) demonstrates that the DNCL's AI adaptivity meaningfully augments human-centered instruction, consistent with constructivist, scaffolding, and metacognitive learning theories.

The DNCL's framework reflects core modern educational theory. As emphasized by Bransford et al. (2000) optimal learning environments activate prior knowledge, present meaningful challenges, and provide timely, actionable feedback. The DNCL operationalizes this through its multi-layer design, which was introduced in the Methods section: (1) Diagnostic Input Layer (baseline activation/AI profiling); (2) Pedagogical Hidden Layers (PjBL & scaffolding); (3) Adaptive Engine (AI-driven, real-time personalization); and (4) Reflective Output (digital portfolios, peer review). Anderson's cognitive learning perspective (Almulla, 2020) further stresses that learning entails schema-building and procedural automation, a process accelerated in DNCL by adaptive task matching to each learner's zone of proximal development. As such, the model realizes a "symbiosis" between deep learning as cognitive process and deep learning as computational infrastructure, enabling more powerful human-AI learning partnerships. Critically, findings indicate that AI literacy must be embedded as a transversal competency, not merely a technical add-on, a priority echoed by both UNESCO and OECD (UNESCCO, 2023; OECD, 2023).

Implementation at SMP Tahta Syajar showed that merging all four AI literacy dimensions (knowing, ethics, interaction, creation) into authentic project work improves not only digital skills but also ethical reasoning and deep conceptual transfer (Long & Magerko, 2020; Casal-Otero et al., 2023). For instance, student projects on “Designing an Ethical Chatbot for School” explicitly demonstrated the integration of these dimensions, requiring them to understand how algorithms work (knowing), consider bias in training data (ethics), interact with the model to test outputs (interaction), and create a final prototype (creation). At a policy level, this research advances the objectives of Indonesia’s “Kurikulum Nasional,” particularly its commitment to flexible learning, authentic assessment, and AI-powered personalization. Embedding DNCL within Informatics education supports these aims and offers a theoretically justified, empirically supported route for future national scaling, subject to the limitations noted below.

For transformative scale-up, the study identifies three urgent preconditions: (1) Teacher Professional Development (AI-PCK): Training programs must be strengthened to empower teachers as AI-PCK co-designers and data-literate facilitators (Nurhaliza & Dwi Putri Pramesti, 2025); (2) Local Data Architecture & Ethics: On-premise, privacy-compliant servers must underpin analytics architectures, following international ethical guidelines (Ienca & Vayena, 2020; UNESCO, 2023a); (3) Adaptive Infrastructure Investment: Systems must be hybrid and bandwidth-adaptive to ensure access in resource-constrained contexts (Ratri & Aviyanti, 2025).

At the cross-national level, the study enriches global equity debates in AI in Education by evidencing that context-sensitive, resource-aware AI deployments can support both educational access and quality (Holmes et al., 2022; Estrada-Molina et al. 2024).

Notwithstanding robust results, the single-site quasi-experimental nature constrains generalizability. Future studies should prioritize multi-site RCTs across regional, urban-rural, and high/low-resource settings to test robustness and adaptation. Additionally, longitudinal/mechanistic data (e.g., conceptual gain, tracked by learning analytics or eye-tracking) would clarify long-term impact. Regional comparative studies (ASEAN/SEAMEO) are crucial to map policy, culture, and readiness differentials and inform collaborative curriculum design (Suryadi et al., 2025).

Integrating deep learning pedagogy and technology signals a paradigm shift, positioning AI as a learning partner, not a teacher substitute, to build ethics, creativity, and human judgment alongside digital adaptability. The DNCL is a practically actionable, theoretically rooted model for meaningful digital transformation in Indonesian and global education.

Conclusion

This study demonstrates that integrating deep learning pedagogy with AI-driven adaptive systems through the Deep Neural Curriculum Loop (DNCL) significantly enhances the quality of Informatics education at the Indonesian secondary level. Empirical evidence from SMP Tahta Syajar indicates substantial improvements in creativity ($\eta p^2 = 0.135$) and learning engagement ($\eta p^2 = 0.103$), confirming that the synergistic combination of Project-Based Learning (PjBL), AI-mediated feedback, and reflective portfolios fosters deeper conceptual understanding and stronger affective engagement. These findings empirically support established learning theories, which emphasize the activation of prior knowledge, contextualized challenge, and continuous feedback as core conditions for meaningful learning.

Beyond the field intervention, the Systematic Literature Review reveals that although global research on AI literacy and deep learning between 2020 and 2025 has advanced rapidly in technological terms, it remains pedagogically underintegrated, particularly within Global South contexts. The DNCL model addresses this gap by operationalizing a human-centered AI pedagogy that integrates cognitive depth, ethical awareness, and adaptive technology, demonstrating that well-designed artificial intelligence can meaningfully augment, rather than replace, human teaching and learning processes.

Nevertheless, these findings should be interpreted in light of the study's limitations, including its single-site quasi-experimental design and reliance on adequate digital infrastructure, which constrain generalizability. Despite these limitations, the study contributes theoretically by unifying deep learning as both a cognitive and computational construct, methodologically by applying an embedded mixed-methods approach supported by learning analytics, and practically by offering a concrete, scalable pathway for implementing the Merdeka Belajar policy in alignment with the Profil Pelajar Pancasila's emphasis on critical thinking, creativity, and collaborative problem-solving.

Based on the empirical findings and theoretical framework of this study, four integrated policy directions are proposed to support the sustainable implementation of AI literacy in Indonesian secondary education. At the national level, the Ministry of Education should institutionalize a comprehensive, project-based AI literacy curriculum within Informatics that integrates conceptual understanding, ethical reasoning, practical interaction, and creative production, aligned with Kurikulum Merdeka and the Profil Pelajar Pancasila, while simultaneously implementing mandatory AI Pedagogical Content Knowledge (AI-PCK) programs to strengthen teacher capacity in data-informed, ethical, and adaptive instructional design. At the district and school levels, targeted investment in secure, scalable digital infrastructure and robust data governance frameworks is essential to ensure equity, privacy, and alignment with UNESCO's Ethical AI in Education guidelines and Indonesia's National AI Strategy 2020–2045. At the research level, future studies should prioritize multi-site randomized controlled trials to validate and scale the DNCL model, alongside exploration of generative and explainable AI for formative assessment, thereby enabling the transition from localized innovation to nationally and internationally scalable, human-centered AI integration that aligns with global AI for Education agendas and offers a transferable blueprint for future-ready education across the Global South.

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