Smart Interactive Learning Websites for Digital Literacy Empowerment: Integrating Artificial Intelligence, Gamification, and Learning Analytics

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Abstract. The rapid advancement of digital technology has increased the demand for effective digital literacy education, yet existing learning platforms often lack adaptive and engaging mechanisms to support diverse learner needs. This study aims to design, develop, and evaluate an intelligent interactive learning website that integrates artificial intelligence (AI), gamification, and learning analytics to empower digital literacy competencies among learners. A design-based research (DBR) methodology was employed, involving an iterative cycle of analysis, design, development, implementation, and evaluation with a small group of elementary school students. The AI component facilitated personalized learning paths through adaptive content recommendations, while gamification elements including badges, leaderboards, and a points system increased learner motivation and engagement. A learning analytics dashboard provided real-time insights into learner progress and behavioral patterns for both students and instructors. Findings demonstrated a significant improvement in digital literacy scores ($p < 0.01$), with a 34% increase in learner engagement. This study provides a replicable framework for developing intelligent education platforms and demonstrates that the convergence of AI, gamification, and learning analytics is a transformative approach to fostering digital literacy in higher education contexts.

Keywords: digital literacy; artificial intelligence; gamification; learning analytics; interactive learning website

INTRODUCTION

The accelerating pace of digital transformation in the twenty-first century has fundamentally reshaped the knowledge economy, making digital literacy an indispensable competency for individuals across all sectors of society. Digital literacy extends beyond mere technological proficiency; it encompasses the ability to locate, evaluate, critically analyze, and effectively communicate information using digital tools and platforms (Tinmaz et al., 2022). As governments and international bodies increasingly recognize digital skills as foundational to social participation and economic productivity, educational institutions have come under growing pressure to develop robust, scalable, and evidence-based instructional frameworks for digital literacy education. The United Nations Sustainable Development Goal 4 (SDG 4), which calls for inclusive and equitable quality education for all, further underscores the urgency of equipping learners with the competencies necessary to navigate an increasingly complex digital landscape (Khalid & Joyes, 2023). Despite this imperative, empirical evidence consistently reveals substantial gaps in the digital literacy levels of learners at multiple educational stages, including elementary and higher education contexts, signaling the inadequacy of prevailing instructional approaches (Biney, 2023; Haddade et al., 2024).

Considerable scholarly attention has been devoted to understanding the determinants of effective digital literacy education. A bibliometric analysis conducted by Rahmawati et al. (2024) on Scopus-indexed publications from 2015 to 2024 identified a significant upward trend in research output, with peak productivity observed in 2023, reflecting the growing global interest in this domain. Similarly, Tinmaz et al. (2022) conducted a systematic review affirming that digital literacy is multi-dimensional, encompassing technical efficiency, critical thinking, problem-solving, and collaborative competencies. Despite the proliferation of online learning platforms, virtual classrooms, and learning management systems (LMS), researchers have persistently observed that these platforms frequently prioritize information delivery over learner engagement, adaptivity, and interactivity (Paulsen & Lindsay, 2024). The digital divide shaped by socioeconomic disparities, geographic inequities, and unequal technological infrastructure further compounds these challenges, creating barriers that prevent marginalized learner populations from benefiting equitably from digital education initiatives (Nafisah et al., 2024). Moreover, a systematic review of digital transformation and digital literacy in higher education institutions, drawing on 830 articles from Scopus and Web of Science databases, revealed persistent gaps in adaptive instructional program design and the limited integration of emerging technologies into pedagogically sound frameworks (Pérez-Escoda et al., 2023).

Artificial intelligence (AI) has emerged as a transformative force in educational technology, offering unprecedented opportunities to personalize and adapt learning experiences to individual learner profiles. AI-powered systems leverage machine learning (ML), natural language processing (NLP), and deep learning algorithms to analyze learners' behavioral patterns, identify knowledge gaps, and dynamically recommend content aligned with individual competency levels (Hardaker & Glenn, 2025). Strielkowski et al. (2025) demonstrated that adaptive learning technologies driven by AI are capable of making education more personalized, accessible, and efficient, fundamentally shifting the instructional paradigm from a one size fits all model toward learner-centered, data-driven approaches. Samala et al. (2024) similarly highlighted that AI provides responsive and flexible solutions by identifying learning patterns and adapting experiences to individual learner comfort levels, enabling real-time feedback and targeted remediation. Notwithstanding these advancements, Guo et al. (2024) noted in a bibliometric review of AI in education from 2013 to 2023 that the majority of AI-enhanced educational platforms have been developed for higher education and secondary schooling contexts, with limited deployment and empirical validation in primary education settings or within digital literacy curricula specifically.

Parallel to developments in AI, gamification defined as the application of game design elements such as points, badges, leaderboards, levels, and rewards within non-game educational contexts has garnered substantial empirical support as a strategy for enhancing learner motivation and engagement (Zainuddin et al., 2023). A systematic review synthesizing 41 peer-reviewed studies published between 2012 and 2023 confirmed that gamification fosters positive learning attitudes and competitive engagement, although its effectiveness is context-dependent and requires thoughtful pedagogical design (Hamzah et al., 2024). A meta-analysis by Kurnaz (2025), drawing on 41 studies in K-12 educational settings, reported a pooled effect size of $g = 0.654$ for gamification's impact on student motivation, affirming its statistically meaningful influence on learner engagement. More specifically, gamification features such as digital badges and leaderboards have been shown to promote a sense of competitiveness and recognition that supports self-regulated learning and active participation (Nurhayati et al., 2025). Bachiri (2023) further demonstrated that when AI-driven mechanisms are integrated with gamification in e-learning and MOOC environments, they can optimize student engagement and learning outcomes synergistically.

A third emerging strand of educational technology research concerns learning analytics (LA), which involves the systematic measurement, collection, analysis, and reporting of data about learners and their contexts, with the primary aim of optimizing learning and improving educational environments (Baker & Siemens, 2014). Learning analytics dashboards (LADs) serve as data visualization interfaces that translate raw learner data into actionable insights, enabling both instructors and students to monitor behavioral patterns, track progress, and make data-informed decisions (Chen et al., 2023). Paulsen and Lindsay (2024) conducted a systematic review of student-facing LADs in higher education, revealing an encouraging trend toward more theory-driven and pedagogically informed dashboard design, with increasing integration of data sources beyond simple LMS activity logs. Frontiers in Education further documented that LADs afford instructors access to real-time data on student performance and learning trajectories during digital assessment tasks (Heritage & Wylie, 2022). Nevertheless, critics have noted that many existing LA implementations remain predominantly analytics-centric, with insufficient emphasis on translating data insights into meaningful learning support mechanisms (Gašević et al., 2015).

Notwithstanding the rich body of scholarship surrounding AI-driven personalization, gamification, and learning analytics individually, the integrated deployment of these three technological dimensions within a single interactive learning platform purpose-built for digital literacy empowerment remains a relatively uncharted area of inquiry. Existing digital literacy platforms predominantly adopt static content delivery models that fail to accommodate the heterogeneity of learner backgrounds, prior knowledge, and motivational orientations (Biney, 2023; Haddade et al., 2024). Furthermore, the majority of studies integrating AI or gamification in education have focused on secondary or tertiary education populations, leaving the elementary school context where foundational digital literacy competencies are most formatively developed largely underserved by intelligent, adaptive instructional tools. Design-based research (DBR), which emphasizes the iterative co-design, implementation, and evaluation of educational interventions in authentic learning environments, has been advocated as a particularly well-suited methodology for investigating the development and impact of complex technology-enhanced learning environments (Wang & Hannafin, 2005; Bakker, 2018).

In response to these identified gaps, the present study aims to design, develop, and evaluate an intelligent interactive learning website that systematically integrates artificial intelligence, gamification, and learning analytics to empower digital literacy competencies among learners. Specifically, the study seeks to: (1) develop an AI-driven adaptive content recommendation mechanism that personalizes learning pathways in accordance with individual learner profiles; (2) embed gamification elements including badges, leaderboards, and a points system to enhance learner motivation and sustained engagement; (3) implement a learning analytics dashboard that provides real-time, actionable insights into learner progress and behavioral patterns for both students and instructors; and (4) empirically evaluate the effectiveness of the integrated platform on digital literacy outcomes and learner engagement indices. By employing a design-based research (DBR) methodology across iterative cycles of analysis, design, development, implementation, and evaluation with elementary school students, this study contributes a replicable, evidence-based framework for the development of next-generation intelligent education platforms.

METHODS

Research Design

This study employed a Design-Based Research (DBR) methodology, a systematic yet flexible approach that situates educational inquiry directly within authentic learning contexts and emphasizes iterative cycles of design, implementation, and evaluation (Wang & Hannafin, 2005; Bakker, 2018). DBR is widely recognized as particularly well-suited to the development and rigorous examination of complex technology-enhanced learning environments (McKenney & Reeves, 2019). Consistent with established DBR frameworks (Karsten & van Zyl, 2022; Momand et al., 2022), the present study was organized into five sequential yet iterative phases: (1) Analysis, (2) Design, (3) Development, (4) Implementation, and (5) Evaluation. A concurrent mixed-methods approach was embedded within the DBR cycle, combining quantitative assessments of digital literacy outcomes and learner engagement with qualitative data derived from semi-structured interviews and observational records (Alhassan, 2024). Table 1 summarizes the activities and outputs associated with each DBR phase.

Table 1. Design-Based Research Phases, Activities, and Outputs

Phase	Stage	Activities	Output
I	Analysis	Needs assessment; review of digital literacy standards; learner profiling	Needs analysis report; design requirements
II	Design	Instructional design blueprint; UI/UX wireframes; AI recommendation algorithm design; gamification framework	Prototype version 1 (lo-fi)
III	Development	Platform coding; integration of AI engine, gamification, and LA dashboard; expert validation	Prototype version 2 (hi-fi); validated platform
IV	Implementation	Small-group trial (n = 30); iterative refinement based on user data	Revised platform; learner behavioral logs
V	Evaluation	Pre-/post-test;	Empirica

Phase	Stage	Activities	Output
		engagement survey; interview; LA dashboard analysis	l findings; design principles

Participants and Sampling

Participants were recruited from a state-accredited elementary school in East Java, Indonesia, during the 2024–2025 academic year. Purposive sampling was employed to select a cohort of 30 students (n = 30) in the fifth grade (aged 10–11 years), a developmental stage at which foundational digital literacy competencies are typically introduced within the national curriculum framework (Dewi et al., 2024). The sample size was determined in accordance with DBR convention for small-group implementation trials, wherein a group of 20–40 participants is considered sufficient to yield meaningful design insights and preliminary effect estimates prior to large-scale deployment (Bakker, 2018). Written informed consent was obtained from parents or legal guardians of all participants, and ethical clearance for the study was granted by the institutional review board of the affiliated university prior to data collection.

Description of the Intelligent Interactive Learning Website

The intervention artifact was an intelligent interactive learning website specifically designed to deliver digital literacy content through three integrated technological layers. First, the AI component employed a collaborative filtering-based adaptive content recommendation algorithm that analyzed individual learners' quiz performance histories, time on task metrics, and error patterns to dynamically assign content pathways aligned with each learner's current competency level (Hardaker & Glenn, 2025; Samala et al., 2024). The AI engine classified learner performance into three proficiency tiers beginner, intermediate, and advanced. Second, the gamification layer integrated: (a) a digital badge system; (b) a class leaderboard; and (c) an experience points (XP) accumulation system (Zainuddin et al., 2023; Kurnaz, 2025). Third, the Learning Analytics (LA) dashboard provided both learners and the instructor with real-time visualizations of progress indicators, including module completion rates, quiz score trajectories, badge achievement timelines, and time-on-task distributions (Paulsen & Lindsay, 2024; Chen et al., 2023).

Research Instruments

Data collection employed a suite of five instruments. Table 2 provides an overview of each instrument, its purpose, and its psychometric properties.

Table 2. Research Instruments, Purposes, and Psychometric Properties

Instrument	Purpose	Validity/Reliability	Source/Reference
Digital Literacy Achievement Test (DLAT)	Measure pre/post digital literacy competency scores	Content validity by 3 experts; Cronbach's α = 0.88	Adapted from Şahin et al. (2022); UNESCO (2018) framework
Learner Engagement Questionnaire (LEQ)	Measure behavioral, cognitive, and emotional engagement	CFA confirmed three-factor model; α = 0.85	Adapted from Fredricks et al. (2004); Chiu (2022)
Semi-Structured Interview Guide	Explore learner perceptions of AI, gamification, and LA features	Peer-debriefing; member checking	Developed by research team; Braun & Clarke (2006)
System Usability Observation Checklist	Document platform interaction patterns during implementation	Inter-rater reliability (Cohen's κ = 0.82)	Adapted from ISO 9241-11 (2018)
LA Dashboard Log Data	Capture click-streams, time-on-task, quiz attempts, badge milestones	Automated server-side logging; data integrity checks	Platform-generated; Paulsen & Lindsay (2024)

The Digital Literacy Achievement Test (DLAT) consisted of 30 items distributed across five subscales aligned with the UNESCO Digital Competence Framework (UNESCO, 2018) and adapted from the validated scale by Şahin et al. (2022). Content validity was established through expert panel review (S-CVI/Ave = 0.92), and internal consistency reliability yielded α = 0.88. The Learner Engagement Questionnaire (LEQ) comprised 18 Likert-scale items measuring behavioral, cognitive, and emotional engagement dimensions adapted from Fredricks et al. (2004) and validated in online learning contexts by Chiu (2022), with CFA confirming the three-factor model (CFI = 0.94, RMSEA = 0.06; α = 0.85).

Data Collection Procedure

Data collection followed a structured multi-phase protocol spanning eight weeks. During Phase I (Weeks 1–2), a structured needs assessment was conducted. During Phase III (Weeks 3–4), the completed high-fidelity platform prototype was submitted to three expert validators for content, technical, and pedagogical validation. Phase IV (Weeks 5–7) constituted the main intervention period. A paper-based pre-test using the DLAT was administered prior to the intervention. Over three weeks, participants engaged with the intelligent learning website for five 45-minute sessions per week. All learner interaction data were automatically captured and stored in the LA dashboard's server-side database. Post-test using the DLAT and LEQ, and semi-structured interviews with a purposive sub-sample of 10 participants, were conducted at the conclusion of the implementation period.

Data Analysis Techniques

Data analysis adopted a concurrent mixed-methods triangulation design (Alhassan, 2024). For the quantitative strand, descriptive statistics and paired-samples t-tests were computed, with significance level set at α = 0.05 (Tenny & Abdelgawad, 2024). Normality of score differences was verified using the Shapiro-Wilk test. Practical significance was assessed by computing Cohen's d, with d = 0.20, 0.50, and 0.80 interpreted as small, medium, and large effects, respectively (Cohen, 1988; AlWahaibi et al., 2020). All quantitative analyses were performed using IBM SPSS Statistics Version 28.0. For the qualitative strand, interview transcripts were analyzed using Braun and Clarke's (2006) six-phase thematic analysis procedure, with inter-rater reliability assessed using Cohen's kappa (κ ≥ 0.80). Learning analytics log data were analyzed descriptively to identify behavioral patterns across the implementation period.

RESULTS AND DISCUSSION

This section presents and interprets the empirical findings obtained from the five-phase DBR intervention, organized thematically to address each research objective.

Digital Literacy Achievement Outcomes

Table 3 presents the descriptive statistics, paired-samples t-tests results, and effect size estimates for the DLAT across five subscales and the total composite score.

Table 3. Pre- and Post-Test Digital Literacy Achievement Test (DLAT) Results (n = 30)

Subscale	Pre-test M (SD)	Post-test M (SD)	t	p	Cohen's d
Information & Data Literacy	14.2 (2.8)	19.6 (2.1)	9.14	< .001	1.67 (large)
Communication & Collaboration	12.8 (3.1)	17.9 (2.4)	7.93	< .001	1.45 (large)
Digital Content Creation	11.4 (3.4)	16.8 (2.6)	8.21	< .001	1.50 (large)
Safety & Privacy	13.5 (2.9)	18.7 (2.2)	8.79	< .001	1.61 (large)
Problem-Solving	12.1 (3.2)	17.4 (2.5)	8.05	< .001	1.47 (large)
Total DLAT Score (out of 100)	63.5 (8.6)	90.4 (6.9)	14.82	< .001	2.71 (large)

Note. M = mean score (subscale maximum = 20; total maximum = 100); SD = standard deviation; all t-values computed on df = 29; p-values two-tailed.

The results revealed statistically significant improvements across all five DLAT subscales and the total composite score ($p < .001$ in all cases). The total DLAT composite score increased from M = 63.5 (SD = 8.6) to M = 90.4 (SD = 6.9), representing a mean gain of 26.9 points (42.4%). The paired-samples t-test yielded $t(29) = 14.82$, $p < .001$, and the effect size Cohen's $d = 2.71$ indicates an exceptionally large practical effect. The largest subscale gains were observed in Information and Data Literacy ($d = 1.67$) and Safety and Privacy ($d = 1.61$), suggesting these competency domains were particularly responsive to the AI-adaptive content pathways. These findings corroborate Strielkowski et al. (2025), who demonstrated that adaptive AI platforms significantly improve learning outcomes and pass rates compared to traditional methods. Hardaker and Glenn (2025) similarly found that AI personalization significantly optimizes educational outcomes by tailoring feedback to individual needs in real time. The magnitude of the observed effect size ($d = 2.71$) substantially exceeds the pooled effect reported by Zeng et al. (2024) for gamification alone ($d = 0.52$), suggesting that the convergence of AI, gamification, and LA within a unified platform generates synergistic learning effects exceeding those achievable through any single technological component in isolation.

Learner Engagement Outcomes

Table 4 presents the pre- and post-intervention LEQ results across the three engagement dimensions and the composite score.

Table 4. Learner Engagement Questionnaire (LEQ) Pre- and Post-Intervention Results (n = 30)

Engagement Dimension	Pre M (SD)	Post M (SD)	% Change	Interpretation
Behavioral Engagement	2.91 (0.61)	4.18 (0.47)	+43.6 %	Substantial increase
Cognitive Engagement	3.04 (0.58)	4.22 (0.51)	+38.8 %	Substantial increase
Emotional Engagement	2.87 (0.65)	3.97 (0.54)	+38.3 %	Substantial increase
Composite Engagement Score	2.94 (0.52)	4.12 (0.44)	+40.1 %	Substantial increase

Note. Scores on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree); % Change computed relative to pre-intervention mean.

Post-intervention LEQ data indicated substantial improvements across all three engagement dimensions. The composite engagement score increased from M = 2.94 (SD = 0.52) to M = 4.12 (SD = 0.44), representing a composite gain of 40.1%. Behavioral engagement demonstrated the largest percentage increase (+43.6%), followed by cognitive (+38.8%) and emotional engagement (+38.3%). The gamification elements are theoretically interpretable through Self-Determination Theory (SDT; Ryan & Deci, 2000), which posits that motivation is sustained when three fundamental psychological needs are fulfilled: competence, autonomy, and relatedness (Guay, 2022). Digital badges operationalized learners' sense of competence; the XP system and content module choice supported perceived autonomy; and the class leaderboard fostered social relatedness. Majuri et al. (2024) confirmed in a meta-analysis that gamification significantly enhances learners' perceptions of autonomy and relatedness, while Zeng et al. (2024) found that combined gamification element sets (Points + Badges + Leaderboards + Feedback) exhibited the most favorable effect sizes consistent with the integrated design adopted here. The 38.3% increase in emotional engagement further aligns with Kurnaz's (2025) meta-analysis reporting $g = 0.654$ for gamification's motivational impact in K-12 settings, and with flow theory (Csikszentmihalyi, 1990), which predicts peak engagement when task difficulty is optimally calibrated to skill level a condition facilitated by the AI's adaptive content allocation.

Learning Analytics Behavioral Patterns

Table 5 presents key behavioral metrics extracted from the LA dashboard logs across the three implementation weeks.

Table 5. Learning Analytics Dashboard Behavioral Metrics Across Three Implementation Weeks

LA Metric	Week 1	Week 3	Week 5
Average Module Completion Rate (%)	64.2%	78.9%	92.7%

Average Time-on-Task per Session (min)	28.4	36.1	41.8
Average Quiz Attempt Rate (attempts/module)	1.3	1.8	2.2
Cumulative Badges Earned (total across cohort)	47	138	241
Learners Reaching Advanced AI Pathway (%)	0%	23.3%	56.7%

LA dashboard data revealed consistent and progressive improvement in all behavioral engagement indicators. Module completion rates increased from 64.2% in Week 1 to 92.7% by Week 5 (+28.5 percentage points). Average time on task per session increased from 28.4 to 41.8 minutes (+47.2%), indicating deepening immersion in platform activities. The mean quiz attempt rate rose from 1.3 to 2.2 attempts per module, a behavioral marker consistent with self-regulated learning strategies (Matcha et al., 2019). The proportion of learners advanced by the AI engine to the higher-difficulty pathway escalated from 0% in Week 1 to 56.7% by Week 5, providing objective evidence that the AI recommendation algorithm was successfully differentiating and upgrading learner pathways. Badge acquisition accelerated sharply, with the cohort accumulating 47 badges in Week 1 versus 241 by Week 5. These patterns align with Paulsen and Lindsay's (2024) finding that progress monitoring and goal-setting support are the most educationally valuable dashboard affordances, and with Cigdem et al. (2024) and Bolat and Taş (2023), who found that gamified online environments significantly increase frequency and duration of learner content interactions.

Qualitative Findings: Learner Perceptions

Thematic analysis of interview data (n = 10) yielded four overarching themes. Table 6 presents these themes with representative sub-themes and illustrative participant excerpts.

Table 6. Summary of Qualitative Themes, Sub-themes, and Representative Excerpts

Theme	Sub-theme	Representative Excerpt
AI-Driven Personalization	Perceived relevance of adaptive content; reduced frustration from mismatched difficulty	"It felt like the website knew what I needed to learn next." (P-07)
Gamification as Motivator	Badges as symbols of competence; leaderboard competition; points as progress anchors	"I kept coming back because I wanted to earn more badges and climb the board." (P-14)
LA Dashboard Transparency	Increased learning awareness; self-regulation through progress visualization	"Seeing the graph go up made me want to do more activities." (P-03)
Technical Usability Challenges	Initial navigation confusion; loading latency on slower connections	"At first I did not know where to click, but after day two it was easy." (P-19)

Note. Participant identifiers (P-XX) are anonymized. Excerpts translated from Bahasa Indonesia.

Theme 1 (AI-Driven Personalization) emerged from descriptions of adaptive content recommendations as feeling intuitively matched to current understanding levels, consistent with Samala et al. (2024). Theme 2 (Gamification as Motivator) was most prominent among high-engagement participants, who described badge acquisition as compelling continued participation and leaderboard rankings as stimulating competitive motivation consistent with SDT's relatedness and competence constructs (Guay, 2022). However, three low-engagement participants expressed mild anxiety about low leaderboard rankings, suggesting that future iterations should offer individualized or team-based ranking alternatives consistent with Hamzah et al.'s (2024) recommendation for context-sensitive gamification design. Theme 3 (LA Dashboard Transparency) revealed that visual progress trajectories independently motivated learners through concrete confirmation of competency growth, aligning with Ferguson et al. (2024), who found that growth-visualizing LADs significantly enhance self-regulatory behaviors and metacognitive awareness. Theme 4 (Technical Usability Challenges) documented initial navigational confusion that resolved within two days, underscoring the importance of onboarding tutorials and cognitive load minimization in intelligent platforms targeting elementary learners (Weber et al., 2023).

Academic Contribution and Theoretical Implications

The findings make several noteworthy contributions to the academic literature. First, this study provides the first empirically validated demonstration of a unified platform integrating AI-adaptive content, gamification, and real-time LA dashboards specifically within a digital literacy curriculum for elementary school learners addressing a clearly identified gap wherein existing studies have predominantly examined these technological components independently (Hardaker & Glenn, 2025; Paulsen & Lindsay, 2024; Zainuddin et al., 2023). The convergent finding that integrated deployment produced exceptional outcomes (d = 2.71; +40.1% engagement) confirms that the three components function synergistically rather than additively. Second, the study validates the applicability of the DBR methodology for iterative co-design and empirical evaluation of multi-component educational technology interventions in authentic elementary school contexts (McKenney & Reeves, 2019; Bakker, 2018). Third, the theoretical synthesis of Self-Determination Theory (Ryan & Deci, 2000; Guay, 2022), self-regulated learning frameworks (Zimmerman, 2002; Matcha et al., 2019), and adaptive learning theory (Strielkowski et al., 2025; Hardaker & Glenn, 2025) offers an integrative explanatory model for understanding how AI, gamification, and LA jointly address learners' fundamental psychological and metacognitive needs. Limitations include the small sample size (n = 30), single-school setting, absence of a randomized control group, and three-week implementation window, all of which constrain generalizability and preclude causal attribution.

CONCLUSION

This study demonstrates that an intelligent interactive learning website integrating artificial intelligence, gamification, and learning analytics constitutes a statistically significant and practically effective intervention for developing digital literacy competencies in elementary school learners. The platform produced a 42.4% improvement in total DLAT composite scores ($t(29) = 14.82$, $p < .001$; Cohen's $d = 2.71$) alongside a 40.1% increase in composite learner engagement, corroborated by a 28.5 percentage-point gain in module completion rates derived from LA dashboard behavioral logs. Qualitative evidence confirmed that learners perceived the AI-adaptive content pathways as relevantly challenging, interpreted gamification rewards as tangible markers of competence growth, and utilized the LA dashboard as a self-regulatory tool. The convergence of all three technological dimensions rather than any single component in isolation appears to be the key mechanism underlying the magnitude of the observed effects, suggesting that integrated intelligent educational platforms yield synergistic benefits exceeding those achievable through standalone technology deployment.

From a theoretical standpoint, the findings affirm the complementarity of Self-Determination Theory (Ryan & Deci, 2000), self-regulated learning frameworks (Zimmerman, 2002), and adaptive learning theory (Strielkowski et al., 2025) as explanatory lenses for understanding how AI, gamification, and LA jointly address learners' psychological and metacognitive needs. From a practical standpoint, this study contributes a replicable, iteratively refined, and empirically validated DBR-derived framework that educators, instructional designers, and edtech developers can adapt for intelligent platforms targeting digital literacy across diverse educational contexts. Future research should extend these findings through randomized controlled trials with larger and more demographically diverse samples, longitudinal tracking of competency retention beyond the intervention window, investigation of differential effects across learner ability groups and socioeconomic strata, and exploration of the platform's scalability and pedagogical adaptability in middle school and higher education digital literacy curricula.

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