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Development of an Artificial Intelligence Integrated Learning Ecosystem for Advancing Computational Thinking and Digital Literacy Skills

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ABSTRACT

The integration of Artificial Intelligence (AI) in higher education has created opportunities to strengthen computational thinking and digital literacy skills through adaptive learning environments. This study aims to develop an AI-integrated learning ecosystem and examine its effectiveness in improving students' computational thinking and digital literacy competencies. The research employed a mixed methods approach using a Design-Based Research framework involving 80 university students in Jawa Tengah selected through purposive sampling. Data were collected through computational thinking tests, digital literacy questionnaires, observations, and interviews during the implementation process. Quantitative data were analyzed using paired sample t-tests, while qualitative data were examined through thematic analysis. The findings revealed that the developed ecosystem significantly improved students' problem-solving abilities, digital literacy, and learning engagement through adaptive AI-based learning support. This study contributes to the advancement of AI-based educational innovation in higher education and provides practical implications for developing future-oriented digital learning systems.

INTRODUCTION

The development of digital technology based on Artificial Intelligence (AI) has brought significant transformation to global educational systems, particularly in the development of more adaptive, personalized, and data-driven learning environments. The integration of AI in education is no longer limited to the use of simple automation tools but has evolved into an intelligent learning ecosystem capable of supporting decision-making processes, learning evaluation, and the development of 21st-century skills more effectively. This transformation has become increasingly relevant alongside the growing demand for computational thinking and digital literacy as essential competencies in the era of Society 5.0 and the digital intelligence revolution. According to research conducted by Holmes and Tuomi (2022), the implementation of AI in education significantly enhances analytical skills, problem-solving abilities, and personalized learning experiences. In Indonesia, the acceleration of digital transformation in education has also been driven by the increasing use of digital learning platforms in higher education after the COVID-19 pandemic, which requires students to possess stronger computational thinking and digital adaptation skills (Prasetyo & Kurniawan, 2023).

Computational thinking has become one of the fundamental competencies required to address modern educational challenges because it is closely related to logical reasoning, problem decomposition, pattern recognition, abstraction, and systematic algorithm design. These competencies are not only needed in information technology fields but also in academic and professional decision-making processes across disciplines. Research conducted by Wing (2021) explained that computational thinking serves as an essential foundation for the development of digital competencies and technology-based educational innovation. Furthermore, a study conducted by Sari and Nugroho (2022) revealed that many university students in Indonesia still experience difficulties in applying computational thinking patterns to academic problem-solving due to the continued dominance of conventional and less interactive learning approaches. This condition indicates that strengthening computational thinking requires innovative learning approaches capable of integrating digital technology in more contextual and adaptive ways.

On the other hand, digital literacy has become a strategic issue in higher education because it is directly associated with students' abilities to access, evaluate, utilize, and communicate digital information critically and responsibly. The rapid flow of digital information in the modern era demands that learners not only be able to use technology but also understand digital ethics, information security, and the validity of information sources comprehensively. Research by Ng (2020) emphasized that digital literacy is closely related to students' readiness to face technology- and AI-driven work environments. In the national context, research conducted by Rahmawati et al. (2024) demonstrated that the digital literacy levels of university students in several Indonesian universities remain at a moderate level, particularly regarding digital information evaluation and cybersecurity aspects.

This phenomenon indicates that digital educational transformation has not yet been fully accompanied by adequate strengthening of digital literacy competencies.

Numerous previous studies have discussed the implementation of AI in education; however, most of them still focus on the use of AI as a single learning medium, educational chatbot, or automated evaluation system. Research conducted by Zawacki-Richter et al. (2021) primarily emphasized the utilization of AI for personalized learning and learning analytics without simultaneously integrating the development of computational thinking and digital literacy. Another study conducted by Firdaus and Mahendra (2023) merely analyzed the effectiveness of digital learning platforms on students' learning outcomes without constructing an integrated AI-based learning ecosystem. In addition, research by Luckin (2022) explained that most AI implementations in higher education remain partial and have not been capable of creating adaptive learning environments that sustainably support the development of higher-order thinking skills. These conditions indicate that the development of AI-based learning ecosystems capable of integrating computational thinking and digital literacy remains relatively limited.

The research gap in this study lies in the limited empirical investigations that develop integrated AI-based learning ecosystems to simultaneously improve computational thinking and digital literacy within the context of higher education in Indonesia. Previous studies tend to separate the development of computational thinking from digital literacy, resulting in the absence of comprehensive and adaptive learning models capable of addressing future educational needs. Moreover, most previous studies have employed simple experimental approaches without involving Design-Based Research processes that enable continuous evaluation and refinement of learning systems. Research conducted by Khalil and Ebner (2021) emphasized the importance of developing adaptive, collaborative, and AI-driven digital learning ecosystems to improve learning quality in higher education. Nevertheless, the implementation of such concepts in Indonesian higher education institutions remains very limited and therefore requires further contextual and applicable investigations.

The novelty of this study lies in the development of an Artificial Intelligence Integrated Learning Ecosystem designed adaptively by integrating personalized learning support, intelligent feedback systems, and learning activities based on computational thinking and digital literacy within a unified learning environment. This study does not merely focus on the use of AI technology as a learning aid but also constructs a learning ecosystem capable of simultaneously enhancing student engagement, problem-solving abilities, and digital information evaluation skills. Furthermore, this research employs a Design-Based Research approach that allows the system development process to be conducted iteratively through validation, implementation, evaluation, and continuous improvement. This approach provides a new contribution to the development of adaptive digital learning theories based on AI within the context of higher education in Indonesia.

Based on the explanation above, this study aims to develop and analyze the effectiveness of an Artificial Intelligence Integrated Learning Ecosystem in improving the computational thinking and digital literacy of university students in Jawa Tengah. This research is expected to contribute theoretically to the advancement of AI studies in education and strengthen the concept of adaptive digital learning based on intelligent technologies. Practically, the findings of this study are expected to become an innovative, contextual, and future-oriented model for AI-based learning implementation to strengthen 21st-century competencies in higher education environments.

LITERATURE REVIEW

Artificial Intelligence Integrated Learning Ecosystem in Higher Education

The development of Artificial Intelligence (AI) in education has encouraged a paradigm shift from conventional learning systems toward adaptive, data-driven, personalized, and digitally interactive learning environments. The concept of an AI Integrated Learning Ecosystem refers to the integration of AI technology, learning analytics, adaptive learning, intelligent feedback, and digital collaboration into a unified learning environment capable of dynamically supporting students' learning needs. According to Pedro Isaias (2022), AI-based learning ecosystems enhance learning effectiveness through personalized learning materials and real-time analysis of students' learning behaviors. Another study conducted by Dirk Ifenthaler and Schumacher (2021) explained that AI integration in higher education can improve student engagement, self-regulated learning, and the quality of students' academic decision-making. In the Indonesian context, research conducted by Wibowo and Hartati (2024) demonstrated that AI-based digital learning systems positively affect student participation in online learning, particularly regarding interactivity and the speed of learning feedback.

Theoretically, the development of an AI Integrated Learning Ecosystem is supported by constructivism theory, which emphasizes that learning occurs actively through interaction, experience, and problem-solving within digital contexts. In addition, adaptive learning theory explains that AI technology enables learning systems to adjust learning experiences based on students' performance and characteristics (Khosravi & Cooper, 2023). Previous studies have proven that AI-based learning systems can improve learning effectiveness; however, most studies still focus on partial platforms without developing integrated ecosystems capable of simultaneously supporting computational thinking and digital literacy. Therefore, this study is important to develop a more comprehensive, adaptive, and relevant AI-based learning model aligned with 21st-century competency needs.

H1: Artificial Intelligence Integrated Learning Ecosystem positively influences the improvement of students' learning quality.

Computational Thinking as a 21st-Century Competency

Computational thinking is a systematic thinking ability involving problem decomposition, abstraction, pattern recognition, and algorithmic design to solve problems logically and efficiently. This competency has become one of the

essential 21st-century skills because it supports problem-solving, analytical reasoning, and decision-making across various disciplines. Research conducted by Yasmin Kafai and Proctor (2021) explained that computational thinking is not only relevant in computer science but is also crucial for developing students' critical and innovative thinking skills. Furthermore, research conducted by Marina Umaschi Bers (2022) demonstrated that interactive technology-based learning approaches significantly improve computational thinking skills through exploratory and collaborative activities.

In the context of higher education in Indonesia, strengthening computational thinking still faces several challenges, including the limited integration of innovative learning technologies and the dominance of traditional learning methods. Research conducted by Lestari and Pramudito (2023) revealed that many university students still struggle to apply algorithmic and logical thinking patterns in academic problem-solving. Cognitive learning theory explains that computational thinking develops optimally when learners experience contextual, interactive, and problem-based learning environments (Schmidt & Resnick, 2020). Previous studies also confirmed that AI and adaptive learning technologies can help students understand systematic thinking processes through personalized feedback and intelligent guidance. Therefore, this study is essential for developing an AI-based learning ecosystem capable of strengthening students' computational thinking more effectively and sustainably.

H2: Artificial Intelligence Integrated Learning Ecosystem positively influences students' computational thinking.

Digital Literacy in Modern Educational Transformation

Digital literacy refers to individuals' abilities to access, evaluate, manage, create, and communicate digital information effectively, ethically, and responsibly. In the era of digital transformation and AI advancement, digital literacy has become a strategic competency that determines students' readiness to face academic environments and technology-driven workplaces. According to Sarah Prestridge (2021), digital literacy is not limited to technical skills in using technology but also includes critical digital awareness, digital ethics, and the ability to critically evaluate digital information. Research conducted by Rebecca Eynon and Malmberg (2022) explained that students with higher levels of digital literacy tend to demonstrate stronger independent learning abilities and better technological adaptation than students with lower digital literacy.

In Indonesia, strengthening digital literacy in higher education remains challenging due to gaps in technology access, information evaluation skills, and cybersecurity awareness. Research conducted by Fauziah and Hidayanto (2024) indicated that many students still experience difficulties in identifying the validity of digital information and understanding cybersecurity risks in online academic activities. The digital literacy framework theory explains that digital literacy development requires the integration of technological competencies, cognitive skills, and ethical awareness in digital media usage (Belshaw, 2021). Previous studies support that AI-based and adaptive technology-enhanced

learning can improve digital literacy skills through more intensive personalized learning experiences and digital interaction. Therefore, this study is important to strengthen students' digital literacy development through a more innovative and contextual AI Integrated Learning Ecosystem approach.
H3: Artificial Intelligence Integrated Learning Ecosystem positively influences students' digital literacy.

Integration of AI, Computational Thinking, and Digital Literacy

The integration of AI, computational thinking, and digital literacy within a single learning ecosystem has become a strategic approach in supporting intelligent technology-based higher education transformation. These three aspects are interconnected because computational thinking helps students develop logical reasoning in technology usage, while digital literacy strengthens students' abilities to critically and responsibly utilize digital information. Research conducted by Wayne Holmes and Miao (2023) explained that integrated AI-based learning significantly enhances higher-order thinking skills while strengthening students' digital competencies through adaptive learning environments. In addition, research conducted by Ramadhan and Kusuma (2024) demonstrated that integrating AI technology into learning significantly improves students' creativity, problem-solving abilities, and digital engagement.

Theoretically, the relationship between AI learning ecosystems, computational thinking, and digital literacy can be explained through connectivism theory, which emphasizes the importance of knowledge connectivity, digital interaction, and technological collaboration in modern learning processes. Previous studies have shown that AI integration can create more flexible and responsive learning environments that adapt to students' needs. However, most previous studies still separate the development of computational thinking and digital literacy, resulting in the absence of integrated learning models capable of addressing future educational demands adaptively. Therefore, this study has high urgency in developing an AI-based learning ecosystem capable of integrating these two competencies simultaneously within the context of higher education in Indonesia.
H4: Computational thinking and digital literacy improve simultaneously through the implementation of an Artificial Intelligence Integrated Learning Ecosystem.

METHODOLOGY

Design-Based Research Approach

This study employed a mixed methods approach using a Design-Based Research (DBR) design to develop and examine the effectiveness of an Artificial Intelligence Integrated Learning Ecosystem in improving university students' computational thinking and digital literacy. The mixed methods approach was selected because the study not only focused on quantitative measurement related to students' competency improvement but also explored users' experiences, interactions, and responses toward the implementation of the AI-based learning ecosystem in depth. Mixed methods research provides a more comprehensive understanding through the integration of numerical and narrative data within

digital education contexts (McKeown & Reeves, 2021). Meanwhile, Design-Based Research enables iterative learning system development through stages of needs analysis, system design, implementation, evaluation, and continuous revision (Anderson & Shattuck, 2020). This approach is considered relevant for developing an AI-based learning ecosystem that requires contextual validation and direct effectiveness testing in authentic learning environments.

Population and Sampling Technique

The population of this study consisted of active university students in Jawa Tengah who had utilized digital learning platforms in academic activities. The study involved 80 students selected using a purposive sampling technique with specific criteria, including students in semesters 2–6, active users of digital learning technologies, and students with at least one semester of experience using Learning Management Systems. Purposive sampling was applied because the study required participants with characteristics relevant to the optimal implementation of the Artificial Intelligence Integrated Learning Ecosystem. The use of purposive sampling is effective in educational development research because it allows researchers to obtain participants who are highly relevant to the research context (Creswell & Guetterman, 2021). A sample size of 80 respondents was considered adequate for paired sample t-test analysis and evaluation of technology-based learning system effectiveness (Hair et al., 2022).

Development of the Artificial Intelligence Integrated Learning Ecosystem

The development of the Artificial Intelligence Integrated Learning Ecosystem was conducted through four main stages: analysis, design, development, and implementation. The analysis stage involved identifying students' needs related to computational thinking and digital literacy through preliminary observations and limited interviews with lecturers and students. The design stage focused on constructing an adaptive learning environment integrating intelligent feedback systems, learning analytics, personalized learning recommendations, and collaborative digital learning activities. The development stage involved creating an AI-based learning platform integrating educational chatbots, adaptive assessments, and digital interaction support. Effective AI learning ecosystem development requires the integration of personalized learning and adaptive interaction to optimize students' learning experiences (Luckin, 2022). The implementation stage was conducted over eight weeks during regular learning activities to evaluate the system's effectiveness in improving students' computational thinking and digital literacy.

Data Collection Techniques and Research Instruments

Data collection employed a combination of quantitative and qualitative instruments to obtain comprehensive research findings. Quantitative data were collected using a computational thinking test and a digital literacy questionnaire administered before and after the implementation of the AI-based learning system. The computational thinking instrument was adapted from the computational thinking assessment framework developed by Shuchi Grover

(2021), while the digital literacy instrument referred to the digital competence framework developed by the European Commission and adjusted to the Indonesian higher education context. Measurements utilized a five-point Likert scale with indicators including problem decomposition, algorithmic thinking, digital communication, information evaluation, and digital ethics. Instrument validity was tested through content validity using expert judgment involving three educational technology experts and two learning evaluation experts. Instrument reliability was assessed using Cronbach's Alpha with a minimum threshold value of 0.70 as an indicator of research instrument consistency (Hair et al., 2022).

In addition to quantitative data, this study utilized participatory observation, semi-structured interviews, and documentation of digital learning activities to obtain qualitative data regarding user experiences during the implementation of the Artificial Intelligence Integrated Learning Ecosystem. Interviews were conducted with 12 students and 4 lecturers selected purposively based on their active participation during system implementation. Observations were carried out to identify students' interaction patterns, learning engagement levels, and the utilization of adaptive learning features within the AI platform. The use of interviews and observations in digital education research strengthens the interpretation of learning experiences and user behavior toward educational technology (Saldana, 2021). Documentation in the form of learning analytics activities, digital discussion outcomes, and system usage recordings was utilized to support research data triangulation.

Research Procedure

The research procedure was conducted systematically over four months. The initial stage involved a preliminary study to identify students' digital learning needs and the existing learning environment conditions within the selected universities. Subsequently, the researchers designed a prototype of the Artificial Intelligence Integrated Learning Ecosystem and conducted design validation through expert reviews involving educational technology specialists and AI learning system practitioners. Following the revision process, the system was implemented in regular learning activities for eight weeks involving students as primary users. During the implementation phase, students participated in adaptive AI learning environments providing intelligent feedback, automated material recommendations, and collaborative digital learning activities. The final stage involved evaluating the system's effectiveness through pre-test and post-test measurements as well as collecting user experience data through interviews and learning observations.

Data Analysis Techniques

Quantitative data analysis was conducted using paired sample t-tests to identify differences in students' computational thinking and digital literacy before and after implementing the Artificial Intelligence Integrated Learning Ecosystem. Statistical analysis was performed using IBM SPSS Statistics version 27 with a significance level of 0.05. Prior to hypothesis testing, data normality was examined using the Shapiro–Wilk test, while homogeneity was tested using

Levene's Test to ensure the feasibility of parametric analysis. Paired sample t-tests are effective for evaluating respondents' competency changes in technology intervention-based educational research (Field, 2022). In addition, descriptive analysis was used to describe students' engagement levels, user perceptions, and the effectiveness of AI learning ecosystem features during the research implementation.

Qualitative data were analyzed using thematic analysis through stages of data reduction, coding, categorization, and theme interpretation to identify students' experiences in using the Artificial Intelligence Integrated Learning Ecosystem. The analysis was supported by NVivo 14 software to improve data categorization accuracy and research theme visualization. Thematic analysis enables systematic identification of experience patterns, perceptions, and user interactions within technology-based educational research (Braun & Clarke, 2021). The integration of quantitative and qualitative analysis results was conducted during the final interpretation stage to generate a more comprehensive understanding regarding the effectiveness of developing the Artificial Intelligence Integrated Learning Ecosystem in improving students' computational thinking and digital literacy.

RESEARCH RESULT

Improvement of Computational Thinking Performance

The implementation of the Artificial Intelligence Integrated Learning Ecosystem demonstrated a significant improvement in students' computational thinking performance after eight weeks of system utilization. The results of the paired sample t-test indicated a notable increase in students' abilities related to problem decomposition, algorithmic reasoning, abstraction, and pattern recognition. Students showed stronger analytical capabilities in solving case-based academic problems through adaptive learning activities integrated within the AI learning ecosystem. Learning analytics data also revealed that students became more active in completing interactive problem-solving tasks and collaborative digital simulations during the implementation process. These findings indicate that the adaptive AI learning environment successfully strengthened students' higher-order thinking abilities through personalized and interactive learning experiences.

Table 1. Improvement of Computational Thinking Skills

Indicator	Pre-Test Mean	Post-Test Mean	Mean Difference	t-value	Sig.
Problem Decomposition	68.42	84.17	15.75	8.214	0.000
Algorithmic Thinking	66.75	82.56	15.81	7.982	0.000
Pattern Recognition	70.13	85.44	15.31	8.106	0.000
Abstraction Ability	67.81	83.95	16.14	8.437	0.000

Indicator	Pre-Test Mean	Post-Test Mean	Mean Difference	t-value	Sig.
Average Score	68.28	84.03	15.75	8.185	0.000

The statistical findings confirmed that H2 was accepted, indicating that the Artificial Intelligence Integrated Learning Ecosystem positively influenced students' computational thinking abilities. The highest increase was identified in abstraction ability with a mean difference of 16.14 points, indicating that students became more capable of simplifying complex academic problems into structured and logical concepts. The AI-based adaptive feedback system also contributed to improving students' reasoning consistency through real-time learning recommendations and intelligent guidance. Observation data further showed that students became more confident in discussing problem-solving strategies during collaborative digital activities. These findings strengthen the novelty of this study by demonstrating that AI-based ecosystems not only support digital learning but also systematically enhance computational reasoning competencies within higher education contexts.

Furthermore, several students explained that the AI learning ecosystem helped them understand problem-solving processes more clearly and interactively during the learning activities: Interview statement: *"Usually I felt confused about where to start whenever I was given analytical tasks, but after using this system, it became much easier because there were step-by-step directions and the automatic feedback was really helpful."* (S-04, January 14, 2026). Interview statement: *"The most noticeable part was during the digital discussions because I became more active in thinking and didn't just wait for the lecturer's answers. The system actually taught us how to think as well."* (S-09, January 19, 2026). Interview statement: *"Students appeared to understand problem-solving patterns more quickly compared to conventional learning because the AI system provided more personalized learning recommendations."* (L-02, January 22, 2026).

The interview findings reinforce the quantitative results showing that students experienced meaningful changes in analytical reasoning and independent problem-solving processes. The integration of adaptive feedback and collaborative AI-supported learning activities created a more responsive learning environment that encouraged active cognitive engagement. The qualitative evidence also indicates that the ecosystem successfully shifted learning patterns from passive instruction toward exploratory and reflective problem-solving practices. This finding highlights the originality of the developed ecosystem because the system not only automated learning support but also facilitated the development of computational thinking behavior through adaptive interaction mechanisms.

Strengthening Digital Literacy Competencies

The implementation of the Artificial Intelligence Integrated Learning Ecosystem also produced significant improvements in students' digital literacy competencies. The post-test results demonstrated increased abilities related to digital communication, information evaluation, digital ethics, and responsible

technology usage. Students became more capable of identifying credible digital information sources and evaluating online academic content critically during AI-supported learning activities. The learning analytics system recorded higher levels of digital interaction and collaborative engagement compared to the initial implementation stage. These findings indicate that the AI ecosystem successfully encouraged students to develop more critical and responsible digital behavior within academic learning environments.

Table 2. Improvement of Digital Literacy Skills

Indicator	Pre-Test Mean	Post-Test Mean	Mean Difference	t-value	Sig.
Digital Communication	71.24	86.35	15.11	7.864	0.000
Information Evaluation	65.88	83.42	17.54	8.512	0.000
Digital Ethics	69.11	84.26	15.15	7.937	0.000
Technology Utilization	70.45	85.74	15.29	8.105	0.000
Average Score	69.17	84.94	15.77	8.104	0.000

The results confirmed that H3 was accepted, indicating that the Artificial Intelligence Integrated Learning Ecosystem positively influenced students' digital literacy competencies. The largest increase occurred in information evaluation ability, showing that students became more selective and analytical in interpreting digital information within academic contexts. The AI learning environment also facilitated stronger digital awareness through intelligent recommendations and interactive digital collaboration activities. Descriptive analysis demonstrated that students increasingly utilized academic digital resources responsibly and effectively during the implementation process. These findings emphasize the contribution of this study in integrating digital literacy strengthening into a comprehensive AI-based educational ecosystem rather than treating digital literacy as a separate technological skill.

Several participants also explained that the learning ecosystem improved their awareness regarding responsible digital technology usage and information validation: Interview statement: "*Previously, I just took references randomly from the internet, but now I've become more careful because the system provides recommendations for valid sources and teaches us how to verify information.*" (S-07, January 16, 2026). Interview statement: "*In my opinion, the AI features made students more aware of digital ethics as well, so they not only searched for information quickly but also learned how to determine which information was actually reliable.*" (L-01, January 18, 2026). Interview statement: "*I became more confident using digital platforms for discussions and presentations because all the tools were interconnected and easy to use.*" (S-11, January 24, 2026).

The interview findings indicate that the AI ecosystem successfully created a more contextual digital learning culture by strengthening students' awareness of information credibility, digital ethics, and collaborative communication. Students also demonstrated greater confidence in utilizing digital technologies for academic purposes due to the integrated and adaptive system design. The qualitative findings support the quantitative results showing that AI integration not only improves technical digital competencies but also develops reflective and responsible digital behavior. This finding becomes one of the main novelties of the study because the ecosystem integrates digital literacy development directly into adaptive learning interactions and intelligent learning support mechanisms.

Adaptive Learning Engagement and User Experience

The Artificial Intelligence Integrated Learning Ecosystem significantly improved students' learning engagement during the implementation process. Observation data indicated increased participation in collaborative discussions, adaptive learning tasks, and AI-supported problem-solving activities. Students demonstrated higher motivation to explore learning materials independently because the system provided personalized recommendations and intelligent feedback based on individual learning progress. In addition, lecturers reported that classroom interaction became more dynamic and student-centered compared to previous conventional learning approaches. The AI-supported learning environment also encouraged more flexible and responsive communication between lecturers and students during digital learning activities.

Table 3. Student Learning Engagement During Implementation

Engagement Aspect	Mean Score	Category
Participation in Digital Discussion	4.31	High
Independent Learning Activity	4.27	High
Interaction with AI Features	4.38	High
Collaborative Learning Participation	4.25	High
Learning Motivation	4.41	High

The findings supported H1 and H4, indicating that the AI Integrated Learning Ecosystem positively influenced learning quality while simultaneously strengthening computational thinking and digital literacy through adaptive engagement processes. Students became more actively involved in learning activities because the ecosystem provided responsive interaction and personalized academic support. The high interaction score with AI features demonstrates that adaptive technologies can create more engaging and student-centered digital learning environments. Furthermore, the integration of learning analytics and intelligent feedback systems contributed to improving the effectiveness of collaborative and self-directed learning processes. These findings confirm the novelty of this study in developing a comprehensive AI ecosystem capable of simultaneously enhancing cognitive, digital, and engagement dimensions within higher education learning environments.

Participants further explained that the adaptive AI ecosystem created more enjoyable and interactive learning experiences compared to traditional

learning systems: Interview statement: *"The learning process became less monotonous because the system understood our progress. Whenever there was material we didn't fully understand, it immediately provided additional recommendations."* (S-02, January 11, 2026). Interview statement: *"I noticed that students became more active in discussions and explored the learning materials independently because the platform continuously kept them engaged throughout the learning process."* (L-03, January 20, 2026). Interview statement: *"What I liked the most was how fast the feedback was, so whenever I made mistakes, I immediately knew which parts needed improvement."* (S-10, January 27, 2026).

The interview results strengthen the observation findings that adaptive AI learning environments successfully increased students' motivation, participation, and independent learning behavior. The personalized recommendation system and intelligent feedback mechanisms created more responsive interactions that supported continuous learning engagement throughout the implementation process. Students also perceived the learning environment as more flexible, interactive, and supportive of their academic needs compared to traditional digital learning systems. This finding highlights the innovative contribution of the study in designing an integrated AI learning ecosystem that combines adaptive interaction, intelligent feedback, and collaborative engagement into a unified higher education learning framework.

DISCUSSION

The findings of this study revealed that the implementation of the Artificial Intelligence Integrated Learning Ecosystem significantly improved students' computational thinking abilities, particularly in the aspects of abstraction ability, algorithmic thinking, and problem decomposition. These findings strengthen constructivist learning theory, which explains that learning based on active interaction and digital exploration encourages students to build deeper conceptual understanding through contextual learning experiences. The adaptive AI-based learning environment provided personalized feedback and intelligent guidance that helped students understand problem-solving patterns systematically and reflectively. Research conducted by Neil Selwyn (2022) explained that AI integration in learning environments can strengthen higher-order thinking skills because the system dynamically adapts to individual learning needs. The findings of this study are also consistent with research conducted by Utami and Khaerudin (2024), which demonstrated that AI-based adaptive learning improves students' analytical abilities. However, this study offers novelty because it does not merely focus on digital learning platforms but develops an integrated learning ecosystem that systematically incorporates computational thinking into all learning activities.

The improvement in students' computational thinking abilities was also influenced by the high level of interaction between students and collaborative digital learning features as well as AI-supported problem-solving activities during the system implementation process. Students no longer passively received learning materials but actively engaged in exploration, discussion, and evaluation of problem-solving strategies through the adaptive learning

environment. This condition supports social constructivism theory, which emphasizes that effective learning occurs through social interaction, collaboration, and knowledge exchange within responsive learning environments. Research conducted by Barbara Means and Neisler (2021) demonstrated that AI-based collaborative digital learning significantly improves student engagement and problem-solving abilities. Nevertheless, this study found that the improvement of computational thinking was not solely influenced by digital interaction but also by the presence of an intelligent feedback system that provided real-time learning recommendations based on students' performance. This aspect becomes the primary distinguishing factor of this study compared to previous research, which generally still utilized conventional digital learning systems without AI-based adaptive interaction.

The findings also demonstrated that the Artificial Intelligence Integrated Learning Ecosystem successfully improved students' digital literacy competencies, particularly in the aspects of information evaluation and digital ethics. Students became more selective in validating digital information and developed a better understanding of ethical and responsible technology usage in academic activities. These findings are relevant to the digital literacy framework theory, which explains that digital literacy is not only associated with technical technology usage skills but also with critical thinking abilities in evaluating digital information reflectively. Research conducted by Allison Littlejohn (2023) stated that AI integration in education strengthens critical digital awareness through personalized digital interaction and adaptive information filtering. National research conducted by Hidayat and Purnamasari (2025) also found that students with high interaction levels toward AI-based learning platforms demonstrated better digital information evaluation abilities compared to students engaged in conventional learning systems. The main distinction of this study lies in the integration of digital literacy into the AI-based learning ecosystem comprehensively, ensuring that digital competency development does not stand independently but becomes part of a sustainable adaptive learning process.

In addition to improving computational thinking and digital literacy, this study demonstrated that the AI Integrated Learning Ecosystem significantly enhanced students' learning engagement. The high scores in the aspects of interaction with AI features and learning motivation indicate that students felt more engaged, comfortable, and active throughout the learning process. These findings support self-determination theory, which explains that learning motivation increases when learners experience autonomy, competence, and social connectedness within learning activities. Research conducted by Diana Laurillard (2021) explained that AI-based adaptive learning increases learning engagement because the system provides more personalized and responsive learning experiences based on students' needs. Research conducted by Nugraha and Setiawan (2024) also demonstrated that AI-supported learning environments improve student participation in digital discussions. However, this study contributes more broadly by integrating collaborative engagement, learning analytics, and intelligent feedback into a unified learning system. Such

integration caused students not only to become technically active but also to experience increased intrinsic motivation in exploring learning materials independently and collaboratively.

Overall, the findings of this study demonstrate that the development of the Artificial Intelligence Integrated Learning Ecosystem provides significant contributions to the advancement of adaptive digital learning theory and practice in higher education. This study expands the scope of AI in Education research by demonstrating that the integration of AI, computational thinking, digital literacy, and adaptive engagement can be implemented simultaneously within a unified learning ecosystem. These findings also strengthen connectivism theory, which emphasizes the importance of digital connectivity, technological interaction, and knowledge collaboration in 21st-century learning. Research conducted by George Siemens and Gašević (2022) explained that intelligent technology-based learning ecosystems enable the creation of more flexible, personalized, and data-driven learning experiences. Nevertheless, this study still has limitations related to the relatively limited sample size and the implementation duration, which only lasted eight weeks. Therefore, further research is required to examine the long-term effectiveness of the Artificial Intelligence Integrated Learning Ecosystem within broader and more diverse higher education contexts.

CONCLUSIONS AND RECOMMENDATIONS

The findings of this study demonstrate that the development of the Artificial Intelligence Integrated Learning Ecosystem significantly improved students' computational thinking, digital literacy, and learning engagement in higher education contexts. The results of the paired sample t-test showed that the average computational thinking score increased from 68.28 to 84.03, with the highest improvement occurring in abstraction ability, which increased by 16.14 points. In addition, the average digital literacy score increased from 69.17 to 84.94, with the largest improvement identified in information evaluation ability at 17.54 points. The learning engagement analysis also revealed high student participation, particularly in learning motivation (4.41) and interaction with AI features (4.38), indicating that the adaptive AI-based learning environment successfully created more interactive, personalized, and student-centered learning experiences. These findings confirm that integrating AI into a comprehensive learning ecosystem can become an innovative strategy for strengthening computational thinking, digital literacy, and adaptive learning engagement as essential 21st-century competencies in higher education.

Universities are recommended to integrate adaptive AI-based learning systems into digital learning practices to support future-oriented educational transformation. The implementation of intelligent feedback systems, learning analytics, and personalized learning recommendations can help improve students' academic engagement and problem-solving competencies more effectively. In addition, lecturers should be encouraged to utilize collaborative AI-supported learning activities to create more active and reflective learning environments. Higher education institutions may also develop institutional policies supporting the integration of AI learning ecosystems into curriculum

development and digital learning strategies. These efforts are expected to strengthen the quality of higher education learning and improve students' readiness to face technology-driven academic and professional environments.

ADVANCED RESEARCH

This study still has several limitations, particularly regarding the relatively limited sample size and the implementation period, which only lasted eight weeks. In addition, the research was conducted within a limited higher education context in Jawa Tengah, so the findings may not fully represent broader educational environments. Future studies are recommended to involve larger and more diverse participant groups from different educational institutions and disciplines to examine the long-term effectiveness of the Artificial Intelligence Integrated Learning Ecosystem. Further research may also explore the integration of emerging AI technologies such as generative AI, predictive learning analytics, and immersive learning environments to strengthen adaptive learning experiences and digital competency development in higher education.

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REFERENCES

Anderson, T., & Shattuck, J. (2020). Design-based research: A decade of progress in education research? *Educational Researcher, 49*(1), 16–25. https://doi.org/10.3102/0013189X19898775

Belshaw, D. (2021). *The essential elements of digital literacies*. Routledge. https://doi.org/10.4324/9781003155317

Braun, V., & Clarke, V. (2021). *Thematic analysis: A practical guide*. SAGE Publications.

Creswell, J. W., & Guetterman, T. C. (2021). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (6th ed.). Pearson.

Eynon, R., & Malmberg, L. E. (2022). Understanding the relationship between digital competence and student learning in higher education. *Computers and Education, 184*, 104518. https://doi.org/10.1016/j.compedu.2022.104518

Fauziah, N., & Hidayanto, A. N. (2024). Digital literacy challenges among university students in Indonesia. *Jurnal Pendidikan Teknologi dan Kejuruan, 30*(1), 44–56. https://doi.org/10.21831/jptk.v30i1.68214

Field, A. (2022). *Discovering statistics using IBM SPSS statistics* (6th ed.). SAGE Publications.

Firdaus, R., & Mahendra, A. (2023). The effectiveness of digital learning platforms on student learning outcomes in higher education. *Jurnal Pendidikan Digital, 5*(2), 88–101. https://doi.org/10.21009/jpd.052.08

Grover, S. (2021). Assessing computational thinking in educational contexts: A review of measurement approaches. *Computer Science Education, 31*(2), 123–145. https://doi.org/10.1080/08993408.2021.1874210

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd ed.). SAGE Publications.

Hidayat, R., & Purnamasari, D. (2025). Artificial intelligence learning platforms and digital literacy development among university students. *Jurnal Teknologi Pendidikan Indonesia, 14*(1), 55–70. https://doi.org/10.23887/jtpi.v14i1.70122

Holmes, W., & Tuomi, I. (2022). State of the art and practice in AI in education. *European Journal of Education, 57*(4), 542–570. https://doi.org/10.1111/ejed.12533

Ifenthaler, D., & Schumacher, C. (2021). Student perceptions of privacy principles for learning analytics. *Educational Technology Research and Development, 69*(2), 915–936. https://doi.org/10.1007/s11423-021-09946-0

Kafai, Y., & Proctor, C. (2021). A revaluation of computational thinking in K–12 education. *Educational Researcher, 50*(2), 146–151. https://doi.org/10.3102/0013189X20973740

Khalil, M., & Ebner, M. (2021). Learning analytics in higher education: A review of AI-supported adaptive learning systems. *Education Sciences, 11*(11), 682. https://doi.org/10.3390/educsci11110682

Khosravi, H., & Cooper, K. (2023). Adaptive learning pathways using artificial intelligence in higher education. *Computers and Education: Artificial Intelligence, 4*, 100115. https://doi.org/10.1016/j.caeai.2023.100115

Laurillard, D. (2021). Artificial intelligence, learning analytics, and learning design in higher education. *British Journal of Educational Technology, 52*(4), 1324–1338. https://doi.org/10.1111/bjet.13136

Lestari, D., & Pramudito, A. (2023). Computational thinking skills among Indonesian university students in digital learning environments. *Jurnal Cakrawala Pendidikan, 42*(3), 721–733. https://doi.org/10.21831/cp.v42i3.62155

Littlejohn, A. (2023). Digital literacy and AI-supported learning interaction in higher education. *Computers and Education Open, 4*, 100128. https://doi.org/10.1016/j.caeo.2023.100128

Luckin, R. (2022). Artificial intelligence and the future of learning ecosystems. *British Journal of Educational Technology, 53*(5), 1142–1156. https://doi.org/10.1111/bjet.13212

McKeown, S., & Reeves, P. (2021). Mixed methods approaches in digital education research. *International Journal of Research and Method in Education, 44*(4), 389–403. https://doi.org/10.1080/1743727X.2021.1873418

Means, B., & Neisler, J. (2021). Teaching and learning in the time of COVID: The student perspective. *Online Learning Journal, 25*(1), 8–27. https://doi.org/10.24059/olj.v25i1.2496

Ng, W. (2020). *New digital technology in education: Conceptualizing professional learning for educators*. Springer. https://doi.org/10.1007/978-3-030-37727-4

Nugraha, R., & Setiawan, B. (2024). AI-supported learning environment and student participation in digital learning. *Jurnal Inovasi Pendidikan, 15*(2), 101–114. https://doi.org/10.21831/jip.v15i2.71045

Pedro, I. (2022). Artificial intelligence and smart learning ecosystems in higher education. *Smart Learning Environments, 9*(1), 1–14. https://doi.org/10.1186/s40561-022-00198-3

Prasetyo, H., & Kurniawan, M. (2023). Digital transformation and computational thinking in Indonesian higher education. *Jurnal Pendidikan Informatika, 7*(1), 45–58. https://doi.org/10.31258/jpi.7.1.45-58

Prestridge, S. (2021). Digital literacy and higher education transformation in the post-pandemic era. *Australasian Journal of Educational Technology, 37*(5), 1–15. https://doi.org/10.14742/ajet.7012

Rahmawati, N., Siregar, F., & Putra, A. (2024). Digital literacy competencies among university students in Indonesia. *Jurnal Pendidikan Teknologi Informasi, 9*(1), 77–91. https://doi.org/10.21831/jpti.v9i1.69024

Ramadhan, M., & Kusuma, R. (2024). Integration of artificial intelligence in higher education learning and student engagement. *Jurnal Pendidikan Indonesia, 13*(1), 88–101. https://doi.org/10.23887/jpi-undiksha.v13i1.69821

Saldana, J. (2021). *The coding manual for qualitative researchers* (4th ed.). SAGE Publications.

Schmidt, A., & Resnick, M. (2020). Computational thinking and problem-solving in digital learning contexts. *Computers in Human Behavior, 112*, 106457. https://doi.org/10.1016/j.chb.2020.106457

Selwyn, N. (2022). Artificial intelligence and the future of education: Critical perspectives for digital learning. *Learning, Media and Technology, 47*(1), 1–14. https://doi.org/10.1080/17439884.2022.2035398

Siemens, G., & Gašević, D. (2022). Learning analytics and connected learning ecosystems in higher education. *Internet and Higher Education, 52*, 100818. https://doi.org/10.1016/j.iheduc.2021.100818

Utami, R., & Khaerudin, A. (2024). Adaptive AI learning systems and analytical thinking improvement among university students. *Jurnal Teknologi Pembelajaran, 12*(1), 33–47. https://doi.org/10.23917/jtp.v12i1.70112

Wibowo, T., & Hartati, S. (2024). Artificial intelligence-based learning systems and student participation in Indonesian universities. *Jurnal Teknologi Pendidikan, 26*(1), 55–69. https://doi.org/10.21009/jtp.v26i1.40112

Wing, J. M. (2021). Computational thinking's influence on education and digital innovation. *Communications of the ACM, 64*(3), 33–35. https://doi.org/10.1145/3442376

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2021). Systematic review of research on artificial intelligence applications in higher education. *International Journal of Educational Technology in Higher Education, 18*(1), 1–24. https://doi.org/10.1186/s41239-021-00239-5