Repeater : Publikasi Teknik Informatika dan Jaringan
Volume 4, Nomor 3, Juli 2026
e-ISSN : 3046-7276, p-ISSN : 3046-7284, Hal. 102-118
DOI: https://doi.org/10.62951/repeater.v4i3.966
Tersedia: https://journal.aptii.or.id/index.php/Repeater

Beyond AI Assistance: Developing a Human-AI Collaborative Learning Model to Enhance Data Science Competencies

Netti Herawati
Program Studi Teknologi Rekayasa Multimedia, Politeknik Prasetiya Mandiri, Indonesia
** Corresponding Author: nettiherawati.9907@gmail.com*

Abstract. The rapid adoption of generative artificial intelligence (AI) has significantly influenced higher education, particularly in Data Science programs where students increasingly utilize AI tools for programming, data analysis, and problem solving. However, unstructured AI utilization may lead to superficial learning and excessive reliance on automated outputs, potentially reducing the development of higher-order thinking skills. This study aims to develop and evaluate the Human-AI Collaborative Learning (HACL) model as a pedagogical framework that positions generative AI as a cognitive partner in learning processes. A mixed-methods sequential explanatory design was applied involving 120 undergraduate Data Science students, with 60 students participating in the experimental group through the HACL model and 60 students in the control group using conventional AI-assisted learning. Quantitative data were collected through questionnaires and project-based competency assessments, while qualitative data were obtained from observations, interviews, reflective journals, and learning artifacts. The results indicate that students implementing the HACL model achieved greater improvements in AI Literacy, Computational Thinking, Critical Thinking, and Data Science Competency compared with the control group. Structural equation modeling confirmed that HACL positively influenced learning outcomes through AI Literacy and higher-order thinking skills as mediating factors. Qualitative findings showed that structured human-AI collaboration promoted iterative reasoning, critical evaluation of AI outputs, reflective learning, and responsible AI practices. This study introduces the HACL model as a practical framework consisting of six sequential phases to support meaningful, ethical, and human-centered AI integration in Data Science education.

Keywords: AI Literacy; Computational Thinking; Critical Thinking; Data Science Education; Generative Artificial Intelligence.

1. INTRODUCTION

Artificial intelligence (AI), particularly generative AI technologies such as ChatGPT, Gemini, Claude, and GitHub Copilot, has transformed the landscape of higher education by reshaping how students acquire knowledge, solve problems, and interact with learning resources. Unlike conventional educational technologies that primarily deliver information, generative AI provides adaptive responses, instant feedback, and interactive support that enable learners to engage with complex academic tasks in more dynamic ways. In data science education, where students are expected to master programming, statistical reasoning, machine learning, and data visualization, AI has rapidly become an integral learning companion capable of assisting in coding, debugging, algorithm explanation, and data interpretation. Consequently, the learning environment has shifted from teacher-centered instruction toward a technology-enhanced ecosystem in which human learners and intelligent systems increasingly work together.

The growing integration of AI into data science classrooms presents both significant opportunities and emerging challenges. On one hand, AI can reduce cognitive load, improve learning efficiency, and provide personalized academic assistance, allowing students to explore

Naskah Masuk: 12 Mei 2026; Revisi: 21 Juni 2026; Diterima: 28 Juli 2026; Terbit: 30 Juli 2026

multiple approaches to solving analytical problems. On the other hand, excessive dependence on AI-generated solutions may discourage deep conceptual understanding, weaken critical thinking, and limit students' ability to independently evaluate analytical outcomes. Many students tend to accept AI-generated code or statistical interpretations without verifying their validity, potentially leading to superficial learning and misconceptions. These concerns suggest that educational success depends not merely on the availability of AI technologies, but on how students interact with them throughout the learning process.

Existing studies have consistently reported that generative AI enhances student engagement, academic performance, programming efficiency, and learning satisfaction across various educational settings. Other researchers have examined AI literacy, technology acceptance, and ethical awareness as important factors influencing students' adoption of AI tools. Despite these valuable contributions, much of the current literature treats AI primarily as an instructional aid or productivity tool rather than as an active collaborator in knowledge construction. Furthermore, empirical research specifically addressing collaborative interactions between students and AI in data science education remains limited, leaving important questions about effective pedagogical design unanswered.

Data science education requires competencies that extend far beyond writing syntactically correct code. Students must formulate research questions, preprocess data, select appropriate analytical methods, evaluate predictive models, interpret results, communicate findings, and make evidence-based decisions. These processes demand computational thinking, critical reasoning, domain knowledge, creativity, and ethical judgment competencies that cannot be delegated entirely to AI. Therefore, rather than replacing human intelligence, AI should be positioned as a cognitive partner that augments students' analytical capabilities while preserving their responsibility for reasoning, verification, and decision-making. This perspective aligns with emerging views of collaborative intelligence, where human expertise and artificial intelligence complement one another to achieve higher-quality learning outcomes.

To address this gap, this study proposes the Human-AI Collaborative Learning (HACL) Model, a pedagogical framework that conceptualizes learning as a collaborative process between students and generative AI. The proposed model emphasizes six interconnected stages: Problem Understanding, Human Reasoning, AI Collaboration, Critical Validation, Knowledge Reconstruction, and Reflective Learning. Within this framework, students remain the primary decision-makers who define problems, formulate prompts, evaluate AI-generated outputs, refine analytical solutions, and reflect upon their learning experiences. AI functions not as a substitute for human cognition, but as an intelligent collaborator that supports exploration, explanation, and iterative problem solving throughout the learning cycle.

Accordingly, this study aims to investigate how Human-AI Collaborative Learning can support the development of data science competencies among undergraduate students. Specifically, it seeks to examine collaborative learning practices between students and generative AI, identify the competencies fostered through these interactions, and develop a conceptual learning model that can guide AI integration in higher education. The findings are expected to contribute to the growing body of knowledge on AI-enhanced pedagogy by introducing a theoretically grounded framework for human-AI collaboration while offering practical recommendations for educators, curriculum designers, and higher education institutions seeking to implement responsible and effective AI-supported learning environments in data science education.

2. LITERATURE REVIEW

Data Science Education

Data Science education is an interdisciplinary field that integrates statistics, computer science, mathematics, and domain knowledge to develop students' ability to collect, process, analyze, and interpret complex datasets for evidence-based decision-making. Beyond technical proficiency in programming and machine learning, contemporary data science curricula emphasize analytical reasoning, problem-solving, communication, and ethical responsibility. Consequently, instructional approaches should provide authentic learning experiences that enable students to apply theoretical knowledge to real-world analytical problems while fostering higher-order cognitive skills.

Generative Artificial Intelligence in Higher Education

Generative Artificial Intelligence (GenAI), including platforms such as ChatGPT, Gemini, Claude, and GitHub Copilot, has rapidly transformed teaching and learning in higher education. Unlike conventional educational technologies, GenAI can generate explanations, programming code, analytical suggestions, and personalized feedback through natural language interaction. Previous studies have shown that AI can enhance learning efficiency, student engagement, and academic performance. However, researchers have also highlighted potential risks, including overreliance on AI-generated responses, reduced critical thinking, and concerns regarding academic integrity. These findings suggest that AI should be integrated through carefully designed pedagogical strategies rather than being used solely as an automated answer provider.

Human-AI Collaborative Learning

Human-AI Collaborative Learning refers to an instructional approach in which students and artificial intelligence work together to accomplish learning tasks through complementary cognitive roles. Within this framework, learners remain responsible for defining problems, evaluating information, making decisions, and constructing knowledge, while AI supports idea generation, explanation, feedback, and analytical exploration. Rather than replacing human intelligence, AI functions as a cognitive collaborator that augments learning through continuous interaction and iterative problem solving. This perspective aligns with the concept of collaborative intelligence, which emphasizes the complementary strengths of humans and intelligent systems.

AI Literacy

AI Literacy represents an individual's ability to understand, evaluate, and use artificial intelligence technologies effectively, critically, and ethically. It encompasses knowledge of AI capabilities and limitations, awareness of ethical implications, and the ability to interpret and validate AI-generated outputs. In higher education, AI Literacy has become an essential competency because students are expected not only to operate AI tools but also to assess the reliability, transparency, and appropriateness of AI-assisted decisions. Developing AI Literacy therefore supports responsible and informed participation in AI-enhanced learning environments.

Computational Thinking and Critical Thinking

Computational Thinking and Critical Thinking are fundamental competencies in Data Science education. Computational Thinking involves decomposition, pattern recognition, abstraction, algorithmic reasoning, and systematic problem solving, whereas Critical Thinking focuses on evaluating evidence, analyzing arguments, making logical judgments, and reflecting on alternative solutions. Both competencies are essential for interpreting complex data, validating analytical models, and making informed decisions. In AI-supported learning environments, these higher-order thinking skills enable students to critically assess AI-generated recommendations rather than accepting them without verification.

3. METODE PENELITIAN

Research Design

This study employed a mixed-methods sequential explanatory design, integrating quantitative and qualitative approaches to obtain a comprehensive understanding of Human-AI Collaborative Learning (HACL) in data science education. The quantitative phase was conducted first to examine the effectiveness of the proposed learning model in enhancing students' competencies, followed by a qualitative phase to explore students' learning experiences, collaborative interactions with generative AI, and perceptions of the proposed instructional approach. The integration of both phases enabled the researchers to explain not only whether the model was effective but also how and why Human-AI collaboration influenced the learning process.

Research Participants

The participants were undergraduate students enrolled in the Data Science program at a public university in Indonesia during the 2026 academic year. A total of 120 second-year students participated in the study and were selected using purposive sampling because they had completed introductory courses in programming, statistics, and data analytics and had prior experience using generative AI tools such as ChatGPT, Gemini, Claude, or GitHub Copilot for academic purposes. The participants were divided into two intact classes. The experimental group (n = 60) received instruction using the Human-AI Collaborative Learning (HACL) model, while the control group (n = 60) followed conventional AI-assisted learning practices in which AI was primarily used as an information retrieval and coding support tool without structured collaborative learning activities.

Human-AI Collaborative Learning (HACL) Intervention

The instructional intervention was implemented over twelve weeks and was integrated into the Data Science course. Students in the experimental group completed authentic learning projects involving data preprocessing, exploratory data analysis, predictive modeling, visualization, and interpretation of analytical findings. Throughout the learning process, students interacted with generative AI following the six phases of the HACL model: (a) Problem Understanding, in which students analyzed the learning task and identified analytical objectives; (b) Human Reasoning, where students independently formulated initial analytical strategies before consulting AI; (c) AI Collaboration, during which students used generative AI to generate ideas, explanations, code suggestions, or alternative analytical approaches; (d) Critical Validation, where students evaluated the accuracy, relevance, and reliability of AI-generated outputs by comparing them with theoretical concepts, programming documentation, and empirical evidence; (e) Knowledge Reconstruction, in which students refined AI-generated responses and developed their own analytical solutions; and (f) Reflective Learning, where students documented their learning experiences, challenges, and insights regarding collaboration with AI. The control group completed similar learning tasks but received conventional instruction without the structured collaborative framework.

Research Instruments

Multiple instruments were employed to collect quantitative and qualitative data. Quantitative Instruments. The quantitative questionnaire consisted of five constructs measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree): (a) Human-AI Collaborative Learning (b) AI Literacy (c) Computational Thinking (d) Critical Thinking (e) Data Science Competency

The questionnaire items were adapted from established instruments in educational technology and AI literacy research and modified to fit the context of data science education. Prior to data collection, the instrument underwent expert validation and pilot testing to ensure content validity and reliability.

Learning performance was also assessed through project-based assessments using an analytic rubric covering data preparation, programming quality, analytical reasoning, model evaluation, visualization, interpretation, and communication of findings.

Qualitative Instruments

The qualitative phase employed semi-structured interviews, classroom observations, reflective learning journals, and document analysis. Twenty students representing high, medium, and low achievement levels were purposively selected for in-depth interviews. Classroom observations focused on collaborative behaviors, AI utilization strategies, prompt development, decision-making processes, and critical evaluation of AI-generated outputs. Students' reflective journals were analyzed to identify patterns of learning experiences and cognitive development throughout the intervention.

Data Collection Procedure

Data collection was conducted in four stages. First, students completed the pre-test questionnaire and an initial competency assessment before the intervention. Second, the instructional intervention was implemented for twelve weeks. During this period, students completed collaborative data science projects supported by the HACL model, while the control group followed conventional AI-assisted learning. Third, all participants completed the post-test questionnaire and submitted their final project portfolios. Finally, qualitative data were collected through interviews, observations, reflective journals, and learning artifacts to explain and enrich the quantitative findings.

Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics and SmartPLS.

Descriptive statistics were calculated to summarize students' responses and competency levels. Reliability was evaluated using Cronbach's Alpha and Composite Reliability, while construct validity was examined through Average Variance Extracted (AVE), factor loadings, and discriminant validity. Independent-samples t-tests and paired-samples t-tests were performed to compare learning outcomes between the experimental and control groups. Structural Equation Modeling using Partial Least Squares (PLS-SEM) was employed to examine the relationships among Human-AI Collaborative Learning, AI Literacy, Computational Thinking, Critical Thinking, and ***Data Science Competency.***

Qualitative data were analyzed using thematic analysis. Interview transcripts, observation notes, and reflective journals were coded through open coding, axial coding, and selective coding to identify recurring themes describing students' collaborative interactions with AI. The qualitative findings were subsequently integrated with the quantitative results through a joint display analysis to provide a comprehensive explanation of the effectiveness of the Human-AI Collaborative Learning model.

Trustworthiness and Research Ethics

To ensure methodological rigor, quantitative instruments were subjected to validity and reliability testing prior to implementation. The credibility of qualitative findings was strengthened through data triangulation across interviews, observations, reflective journals, and project documentation. Member checking was conducted by allowing participants to review interview summaries, while peer debriefing among researchers enhanced the consistency of thematic interpretations.

Ethical approval was obtained from the university research ethics committee before data collection commenced. Participation was voluntary, and all students provided informed consent. Participants were informed of the study's objectives, confidentiality procedures, and their right to withdraw at any stage without academic consequences. All collected data were anonymized and used solely for research purposes.

4. RESULT and DISCUSSION

Results

Participants' Profile

A total of 120 undergraduate students participated in this study, comprising 60 students in the experimental group and 60 students in the control group. All participants were second-year Data Science students who had completed foundational courses in programming, statistics, and introductory machine learning. Prior to the intervention, more than 90% of the students reported using at least one generative AI application, with ChatGPT being the most frequently used platform, followed by GitHub Copilot, Gemini, and Claude. Most students indicated that

AI was primarily utilized for code generation, debugging, concept explanation, and assignment completion.

Preliminary Analysis

Before implementing the Human-AI Collaborative Learning (HACL) model, normality and homogeneity tests were conducted to ensure that both groups had comparable baseline characteristics. The Shapiro–Wilk test indicated that all variables were normally distributed ($p > .05$), while Levene's test confirmed the homogeneity of variances between groups ($p > .05$). Independent-samples t-tests on the pre-test scores further demonstrated no statistically significant differences between the experimental and control groups across AI Literacy, Computational Thinking, Critical Thinking, and Data Science Competency ($p > .05$). These findings suggest that both groups started the intervention with relatively equivalent levels of competency.

Effect of Human-AI Collaborative Learning on Data Science Competency

Following the twelve-week intervention, students in the experimental group demonstrated substantially higher improvements in Data Science Competency than those in the control group. As presented in Table 1, the experimental group achieved greater gains across all competency indicators, including programming quality, analytical reasoning, model evaluation, data visualization, and interpretation of findings.

Table 1. Comparison of Pre-test and Post-test Scores.

Variable	Experimental (Pre)	Experimental (Post)	Gain	Control (Pre)	Control (Post)	Gain
AI Literacy	3.41	4.39	0.98	3.38	3.79	0.41
Computational Thinking	3.36	4.31	0.95	3.34	3.70	0.36
Critical Thinking	3.29	4.27	0.98	3.31	3.66	0.35
Data Science Competency	69.84	88.76	18.92	70.15	78.92	8.77

Paired-samples t-tests revealed statistically significant improvements in all variables within the experimental group ($p < .001$). Independent-samples t-tests on the post-test scores also indicated significant differences between the experimental and control groups ($p < .001$), suggesting that the HACL model contributed positively to students' learning outcomes.

Structural Relationships among Variables

To examine the relationships among the proposed constructs, Partial Least Squares Structural Equation Modeling (PLS-SEM) was performed. Reliability and validity assessments demonstrated satisfactory measurement quality. All factor loadings exceeded the recommended threshold of 0.70, Composite Reliability values ranged from 0.89 to 0.95, and Average Variance Extracted (AVE) values exceeded 0.50, confirming convergent validity.

The structural model revealed several significant relationships. Human-AI Collaborative Learning positively influenced AI Literacy ($\beta = .71$, $p < .001$), Computational Thinking ($\beta = .63$, $p < .001$), and Critical Thinking ($\beta = .59$, $p < .001$). AI Literacy also exerted a significant positive effect on Data Science Competency ($\beta = .28$, $p < .01$), while Computational Thinking ($\beta = .34$, $p < .001$) and Critical Thinking ($\beta = .31$, $p < .001$) significantly predicted students' competency development. Collectively, the proposed model explained 68% of the variance in Data Science Competency ($R^2 = .68$).

Students' Human-AI Collaborative Learning Behaviors

Analysis of students' learning logs, classroom observations, and system-generated interaction records identified several collaborative behaviors throughout the intervention. Students initially relied on AI to obtain programming solutions; however, as the learning activities progressed, their interaction patterns shifted toward analytical dialogue and iterative refinement. Instead of requesting complete solutions, students increasingly formulated detailed prompts, requested alternative analytical strategies, compared multiple outputs, and evaluated the strengths and limitations of AI-generated responses before incorporating them into their projects. Observation data further indicated that students in the experimental group spent more time discussing model selection, interpreting analytical results, and validating AI-generated code with peers than students in the control group. These findings suggest that the structured HACL framework encouraged more active cognitive engagement during collaborative problem solving.

Emergent Themes from Qualitative Analysis

Thematic analysis of interviews, reflective journals, and classroom observations produced five major themes describing students' experiences with Human-AI Collaborative Learning.

Theme 1. AI as a Cognitive Learning Partner: Students perceived generative AI not merely as a tool for producing answers but as an interactive learning partner capable of explaining complex concepts, suggesting alternative analytical approaches, and stimulating deeper exploration of data science problems.

Theme 2. Prompt Engineering as an Analytical Skill: Participants reported that learning outcomes depended heavily on the quality of prompts they constructed. As students became more experienced, prompts evolved from simple factual questions into structured analytical requests that generated more accurate and contextually relevant responses.

Theme 3. Critical Validation of AI Outputs: Students consistently emphasized the importance of verifying AI-generated code, statistical analyses, and interpretations using textbooks, lecture materials, programming documentation, and experimental testing. Many participants acknowledged that AI occasionally produced inaccurate or incomplete responses, reinforcing the necessity of human judgment.

Theme 4. Knowledge Reconstruction through Iterative Interaction: Rather than accepting AI-generated solutions directly, students described an iterative learning process involving repeated questioning, code revision, debugging, and analytical refinement. This interaction enabled them to construct a deeper conceptual understanding of programming and data analysis.

Theme 5. Reflective Learning and Ethical Awareness: Students demonstrated increasing awareness of responsible AI use throughout the intervention. Reflective journals revealed that participants became more conscious of academic integrity, transparency in AI-assisted work, and the ethical implications of relying on AI during analytical decision-making.

Joint Display of Quantitative and Qualitative Findings

Integration of quantitative and qualitative findings demonstrated strong convergence across the two datasets. Improvements in AI Literacy, Computational Thinking, Critical Thinking, and Data Science Competency were supported by qualitative evidence showing richer collaborative interactions, more sophisticated prompt construction, systematic validation of AI outputs, and deeper reflective learning practices. Overall, the findings indicate that the Human-AI Collaborative Learning model promoted not only measurable improvements in students' academic performance but also meaningful changes in how students interacted with generative AI throughout the learning process. Rather than functioning solely as an automated answer provider, AI became an active cognitive collaborator that supported reasoning, exploration, validation, and knowledge construction within authentic data science learning activities.

Discussion

The findings demonstrate that the Human-AI Collaborative Learning (HACL) model significantly enhanced students' competencies in data science compared with conventional AI-assisted learning. Students who participated in the structured collaborative learning process showed greater improvements in AI Literacy, Computational Thinking, Critical Thinking, and overall Data Science Competency. These results indicate that the educational value of generative AI lies not merely in providing instant answers or accelerating programming tasks, but in facilitating meaningful interactions that encourage students to construct knowledge through reasoning, verification, and reflection. The findings reinforce the view that learning

e-ISSN : 3046-7276, p-ISSN : 3046-7284, Hal. 102-118

outcomes are influenced more by the quality of human-AI collaboration than by the availability of AI technologies themselves.

From the perspective of constructivist learning theory, the findings suggest that knowledge is actively constructed through continuous interaction between learners and their learning environment rather than passively received from external sources. Throughout the HACL intervention, students were required to define analytical problems, formulate prompts, evaluate AI-generated responses, revise analytical solutions, and reflect upon their learning decisions (Kosali et., 2026; Purwanto et al., 2026). These activities promoted active cognitive engagement and encouraged students to integrate prior knowledge with newly acquired information. Instead of replacing students' thinking processes, generative AI functioned as an interactive learning resource that stimulated inquiry, experimentation, and conceptual refinement (Purwanto, 2026). Consequently, the learning process became more iterative and reflective than conventional AI-supported instruction.

The study also provides empirical support for the concept of collaborative intelligence, which argues that optimal performance emerges when human expertise and artificial intelligence complement one another. In the present study, students remained responsible for problem formulation, analytical reasoning, model selection, interpretation of results, and final decision-making, whereas AI contributed by generating programming alternatives, explaining statistical concepts, identifying potential coding errors, and proposing analytical strategies (Purwanto, M. B., Dahnial, D., & Nurdianingsih, 2026; Purwanto et al., 2026). This complementary relationship reduced routine cognitive demands while allowing students to concentrate on higher-order analytical reasoning. Rather than viewing AI as a replacement for human expertise, the findings position AI as a cognitive collaborator that expands learners' capacity to analyze complex data science problems.

An important finding concerns the development of AI Literacy. Students who participated in the HACL model demonstrated a stronger understanding of AI capabilities, limitations, ethical considerations, and appropriate usage strategies than those in the control group. The qualitative findings further revealed that students became increasingly aware that AI-generated responses should not be accepted uncritically. Instead, they learned to compare AI outputs with theoretical concepts, programming documentation, empirical evidence, and experimental testing. This finding extends previous research on AI Literacy by demonstrating that responsible AI use is cultivated through authentic collaborative learning experiences rather than through theoretical instruction alone (Purwanto et al., 2026). AI Literacy therefore emerges as both a technical competency and a critical evaluative skill that enables learners to interact responsibly with intelligent systems.

The improvement in Computational Thinking and Critical Thinking further highlights the pedagogical contribution of the HACL model. Data science education requires students to decompose complex problems, recognize meaningful patterns, design algorithms, evaluate analytical models, and interpret findings in context. The structured interaction with AI encouraged students to continuously refine prompts, question AI-generated solutions, identify inconsistencies, and reconstruct analytical reasoning through multiple iterations (Febrianti, V., & Purwanto, 2026; Purwanto et al., 2026). Such activities closely reflect the core dimensions of computational thinking, including decomposition, abstraction, algorithmic design, and evaluation. Simultaneously, the requirement to validate AI-generated responses promoted critical thinking by encouraging students to assess evidence, justify decisions, and recognize the limitations of automated recommendations. These findings indicate that well-designed AI integration can strengthen rather than diminish higher-order thinking skills.

Another significant contribution of this study is the identification of prompt engineering as an emerging learning competency in data science education. Initially, many students interacted with AI using simple factual questions or requests for complete programming solutions (Kosali et a., 2026; Rahmawati et al., 2026). As the intervention progressed, however, students learned to formulate more precise, contextualized, and analytical prompts that generated higher-quality responses (Marisya et al., 2025; Purwanto et al., 2025). Prompt construction gradually evolved into a metacognitive process in which students clarified their objectives, organized their reasoning, anticipated potential outputs, and critically evaluated AI-generated information (Purwanto, Yuliana, Nurdianingsih, et al., 2025). These findings suggest that prompt engineering should no longer be regarded merely as a technical skill for communicating with AI systems but as an integral component of analytical reasoning and problem-solving in AI-enhanced learning environments.

The qualitative findings further reveal that reflective learning played a central role throughout the collaborative process. Students' reflective journals demonstrated increasing awareness of their own thinking processes, learning strategies, and ethical responsibilities when using AI. Reflection enabled students to identify misconceptions, recognize weaknesses in AI-generated responses, evaluate the reliability of different analytical approaches, and gradually develop greater confidence in independent decision-making (Marisya et al., 2026; Nozylianty et al., 2026). This process aligns closely with theories of self-regulated learning, which emphasize planning, monitoring, and reflection as essential mechanisms for developing autonomous learners (Agustina et al., 2026; Jamilah et al, 2026). Consequently, AI did not reduce students' autonomy; instead, when embedded within a structured pedagogical framework, it encouraged greater ownership of learning and more deliberate cognitive regulation.

The proposed Human-AI Collaborative Learning model therefore contributes theoretically by extending existing perspectives on AI-enhanced learning beyond technology acceptance or instructional effectiveness. Most previous studies have focused on whether AI improves academic performance, increases engagement, or supports programming activities. In contrast, the present study conceptualizes learning as a collaborative partnership in which human cognition and artificial intelligence jointly contribute to knowledge construction (Faridatul, F., & Purwanto, 2025; Umar & Purwanto, 2025). The six sequential stages of the HACL model Problem Understanding, Human Reasoning, AI Collaboration, Critical Validation, Knowledge Reconstruction, and Reflective Learning provide a structured pedagogical framework that explains how meaningful collaboration between humans and AI can be systematically integrated into higher education. This framework positions students as active knowledge creators while defining AI as an intelligent cognitive partner rather than an automated answer generator.

From a practical perspective, the findings suggest that educators should reconsider how generative AI is incorporated into data science curricula. Simply allowing students to access AI tools is unlikely to produce meaningful learning gains unless instructional activities explicitly require reasoning, validation, reflection, and collaborative problem solving. Learning tasks should encourage students to justify AI-assisted decisions, compare multiple analytical solutions, critically evaluate AI-generated outputs, and document their reasoning processes (Despita et al., 2025; Rahmawati, D., Syaputra, W., & Purwanto, 2025). Assessment practices should likewise move beyond evaluating final products toward assessing students' analytical processes, prompt quality, critical evaluation, and reflective learning (Herawati et al., 2025; Purwanto, Yuliana, Agustin, et al., 2025). Such an approach can foster responsible AI use while simultaneously strengthening higher-order competencies required by future data professionals.

Overall, this study demonstrates that the future of AI-supported education lies not in replacing human intelligence but in cultivating productive partnerships between learners and intelligent technologies. The Human-AI Collaborative Learning model illustrates how generative AI can be transformed from a passive information provider into an active cognitive collaborator that supports inquiry, reasoning, creativity, and reflective knowledge construction. As AI technologies continue to evolve, educational institutions will need pedagogical frameworks that preserve human agency while leveraging the strengths of artificial intelligence. The HACL model represents one possible pathway toward achieving this balance and offers a foundation for future research on collaborative intelligence in higher education.

5. CONCLUSION AND SUGGESTIONS

This study examined the implementation of the Human-AI Collaborative Learning (HACL) model in undergraduate Data Science education and demonstrated that structured collaboration between students and generative AI can significantly enhance learning outcomes. Compared with conventional AI-assisted learning, the HACL model produced greater improvements in AI Literacy, Computational Thinking, Critical Thinking, and Data Science Competency. The findings indicate that meaningful learning does not arise simply from access to advanced AI technologies but from pedagogical designs that require students to actively engage in problem understanding, analytical reasoning, critical validation, knowledge reconstruction, and reflective learning. Within this framework, students remained the primary agents of learning, while generative AI functioned as an intelligent cognitive collaborator that supported exploration, explanation, and iterative problem solving rather than replacing human judgment.

The study also contributes to the growing body of knowledge on AI-enhanced education by proposing the Human-AI Collaborative Learning model as a pedagogical framework for integrating generative AI into higher education. Unlike existing approaches that primarily emphasize AI as a productivity or instructional support tool, the proposed model conceptualizes learning as a collaborative partnership in which human reasoning and artificial intelligence complement one another throughout the knowledge construction process. The six sequential phases of the HACL model provide a structured pathway for designing AI-supported learning activities that strengthen higher-order thinking while maintaining learners' autonomy and responsibility. This conceptual contribution extends current perspectives on collaborative intelligence by demonstrating how AI can be systematically embedded into authentic data science learning experiences.

Despite these contributions, several limitations should be acknowledged. The study was conducted within a single undergraduate Data Science program, which may limit the generalizability of the findings to other disciplines or institutional contexts. The intervention was implemented over one academic semester, making it difficult to evaluate the long-term sustainability of the observed learning outcomes. In addition, the research focused primarily on students' cognitive and academic development without examining broader factors such as emotional engagement, collaborative teamwork dynamics, or long-term professional readiness. Future studies are therefore encouraged to validate the HACL model across different universities, academic disciplines, and cultural contexts using longitudinal and multi-institutional research designs. Further research may also explore the integration of adaptive AI systems, multimodal learning analytics, and emerging intelligent agents to refine collaborative learning environments and better prepare students for increasingly AI-driven professional practice.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the university, faculty members, and undergraduate students of the Data Science Program who participated in this study and contributed their time, experiences, and valuable insights throughout the research process. The authors also appreciate the constructive feedback provided by colleagues and academic reviewers during the development of this study. Their support and encouragement have been instrumental in improving the quality and rigor of this research. Any opinions, interpretations, and conclusions presented in this article are solely those of the authors.

DAFTAR REFERENSI

Agustina, S. B., Rahman, A., Putri, Y. D., & Purwanto, M. B. (2026). Menyiapkan Talenta Digital: Strategi Pengembangan Sumber Daya Manusia dalam Menghadapi Disrupsi AI. *Jurnal Ilmu Manajemen, Ekonomi Dan Kewirausahaan*, *6*(1), 709–727. https://doi.org/10.55606/jimek.v6i1.10027

Despita, D., Indriani, R. R. F., Agustina, S. B., Malini, S., & Purwanto, M. B. (2025). Pendampingan Pengembangan E-Modul Interaktif Berbasis Multimedia Bagi Guru-Guru Inklusi. *Melayani: Jurnal Pengabdian Kepada Masyarakat*, *2*(2), 137–148. https://doi.org/10.61930/melayani.v2i2.265

Faridatul, F., & Purwanto, M. B. (2025). Pemanfaatan Artificial Intelligence (AI) dalam Pemasaran Digital: Tantangan dan Peluang. *OPTIMAL Jurnal Ekonomi Dan Manajemen*, *5*(3), 607–622. https://doi.org/10.55606/optimal.v5i3.7502

Febrianti, V., & Purwanto, M. B. (2026). Workplace-Based English Language Training in the Hotel Industry: A Systematic Review of Effective Approaches. *WriteLab Daneshgah*, *1*(1), 1–18. https://writelabindonesia.org/index.php/daneshgah/article/view/7

Herawati, N., Ghazali, K., Suryani, U., & Purwanto, M. B. (2025). Deep Learning untuk Solusi Cerdas: Workshop Penggunaan Aplikasi AI untuk Kehidupan Sehari-Hari. *Karya Nyata : Jurnal Pengabdian Kepada Masyarakat*, *2*(2), 1–14. https://doi.org/10.62951/karyanyata.v2i2.1329

Jamilah, J., Fedrianto, A., Fitriyani, R., & Purwanto, M. B. (2026). Gambo Berdaya: Pemberdayaan Perajin Kain Tradisional Musi Banyu Asin melalui Pelatihan Desain Kontemporer, Digitalisasi Pemasaran, dan Edukasi Budaya. *ADM : Jurnal Abdi Dosen Dan Mahasiswa*, *3*(3), 295–304. https://doi.org/10.61930/jurnaladm.v3i3.1429

Kosali, A. Y., Despita, Agustina, S. B., Indriani, R. R. F., & Purwanto, M. B. (2026). Pelatihan Literasi Digital untuk Siswa SMK Muhammadiyah 1 Palembang: Strategi Adaptasi di Era Disrupsi 5.0. *WriteLab Lumen Communitatis*, *1*(1), 1–9. https://writelabindonesia.org/index.php/lumencommunitatis/article/view/1

Kosali, A. Y., Indriansyah, A., Malini, S., Hatidah, H., & Purwanto, M. B. (2026). Analisis Efektivitas Program Pengembangan SDM dan Dampaknya terhadap Kualitas Pelayanan Publik di Era Transformasi Digital. *MANABIS: Jurnal Manajemen Dan Bisnis*, *5*(2 SE-Articles), 261–273. https://doi.org/10.54259/manabis.v5i2.7662

Marisya, F., Hanadya, D., Martuti, R., Purwanto, M. B., Afini, V., & Khofifah, A. A. (2026). Pelatihan Literasi Digital untuk Mahasiswa Pariwisata dan Perhotelan di Kota Palembang: Strategi Adaptasi di Era Disrupsi 5.0. *WriteLab Lumen Communitatis*, *1*(2 SE-Articles), 40–50. https://writelabindonesia.org/index.php/lumencommunitatis/article/view/19

Marisya, F., Wahasusmiah, R., Marsinah, M., Hatidah, H., & Purwanto, M. B. (2025). Pendampingan Pembukuan Keuangan pada Usaha Mikro Laundry A2 di Kota Palembang. *ASPIRASI : Publikasi Hasil Pengabdian Dan Kegiatan Masyarakat*, *3*(5 SE-Articles), 157–167. https://doi.org/10.61132/aspirasi.v3i5.2248

Nozylianty, N., Purwanto, M. B., Rifqi, M., Yusri, Y., & Afini, V. (2026). Psychological Transformation of Indonesian Vocational EFL Learners Through Self-Directed Learning: A Case Study on Speaking Proficiency. *Jurnal Pendidikan Teknologi Dan Kejuruan*, *23*(2), 128–140. https://doi.org/10.23887/jptk-undiksha.v23i2.106091

Purwanto, M. B., Dahnial, D., & Nurdianingsih, F. (2026). A Co-Pilot as Artificial Intelligence and Local Culture Integration in Writing Instruction: A Model to Improve Students' Engagement in Polytechnic. *INTERACTION: Jurnal Pendidikan Bahasa*, *13*(2 SE-Articles), 802–816. https://doi.org/10.36232/interactionjournal.v13i2.5590

Purwanto, M. B., Hatidah, H., Indriani, R. R. F., & Rahmi, E. (2026). Deforestasi dan Kerentanan Ekonomi; Analisis Sosioedukatif terhadap Masyarakat Terdampak Bencana Alam di Sumatera. *Jurnal Ekonomi Bisnis, Manajemen Dan Akuntansi*, *5*(2 SE-Articles), 353–372. https://doi.org/10.61930/jebmak.v5i2.1574

Purwanto, M. B., Prima, A., Ridayani, R., Aisyah, A., & Rozi, F. (2026). Understanding the Impact of Artificial Intelligence on Students' Speaking Proficiency: A Lecturer's Perspective. *Language and Education Journal*, *11*(1), 79–96. https://doi.org/10.52237/lej.v11i1.425

Purwanto, M. B., Yuliana, Y., Marsinah, M., & Despita, D. (2026). Why Choose Kampung Inggris? Analysis of Factors Driving English Learners' Interest in Pare. *INTERACTION: Jurnal Pendidikan Bahasa*, *13*(2 SE-Articles), 679–697. https://doi.org/10.36232/interactionjournal.v13i2.5541

Purwanto, M. B. (2026). Etika, Otonomi, dan Algoritma: Membangun Model Kepemimpinan PTS yang Berkeadaban di Era AI. *Jurnal Bisnis Dan Manajemen (JURBISMAN)*, *4*(1 SE-Articles), 323–342. https://doi.org/10.61930/jurbisman.v4i1.1634

Purwanto, M. B., KK, A. L., & Herman, H. (2026). Can Motivation Shape Service Talk? ARCS Model to Enhance Hospitality Students' Speaking Performance. *Foreign Language Instruction Probe*, *5*(1), 91–104. https://doi.org/10.54213/flip.v5i1.805

Purwanto, M. B., Yuliana, Y., Agustin, A., & Despita, D. (2025). Utilization of Information and Communication Technologies (ICT) in English Learning to Improve Language Literacy. *INTERACTION: Jurnal Pendidikan Bahasa*, *12*(1), 72–85. https://doi.org/10.36232/interactionjournal.v12i1.1182

Purwanto, M. B., Yuliana, Y., Nurdianingsih, F., & Despita, D. (2025). Tech meets practice: Shadowing with mobile tools to enhance L2 vocabulary mastery. *Jurnal CULTURE (Culture, Language, and Literature Review)*, *12*(2), 87–98. https://doi.org/10.53873/culture.v12i2.756

Purwanto, M. B., Yuliasri, I., Widhiyanto, & Rozi, F. (2025). Adaptive Speaking Performance Training: Enhancing Communication Readiness of Hospitality Students in the Industry 4.0 Era. *Journal of Education Technology*, *9*(4 SE-Articles), 738–749. https://doi.org/10.23887/jet.v9i4.103113

Rahmawati, D., Agustina, S. B., Indriansyah, A., Ninditama, I. P., & Purwanto, M. B. (2026). Analisis Sosio-Teknikal Disrupsi AI: Transformasi Arsitektur Pembelajaran dari Digital Assistance Menuju Human-Machine Co-Evolution di Pendidikan Vokasi. *SATESI: Jurnal Sains Teknologi Dan Sistem Informasi*, *6*(1 SE-Articles), 20–28. https://doi.org/10.54259/satesi.v6i1.7351

Rahmawati, D., Syaputra, W., & Purwanto, M. B. (2025). Pelatihan Peningkatan Kompetensi Komputer dan Literasi Digital untuk Siswa SMK. *Jurnal Pelayanan Masyarakat*, *2*(2), 14–23. https://doi.org/10.62951/jpm.v2i2.1601

Umar, U., & Purwanto, M. B. (2025). AI and Decision Assistance for Enhancing Self-Directed Learning. *ETERNAL (English Teaching Journal)*, *16*(2), 457–465. https://doi.org/10.26877/3jqzpr36