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Penerapan Pembelajaran Berbasis Proyek yang Terintegrasi dengan Kecerdasan Buatan untuk Meningkatkan Literasi Kewirausahaan Digital dan Keterlibatan Siswa dalam Pendidikan Ekonomi

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Abstrak

Perkembangan pesat teknologi digital dan kecerdasan buatan (AI) telah memberikan pengaruh yang signifikan terhadap praktik pendidikan tinggi, sehingga menuntut model pedagogis inovatif yang dapat menumbuhkan kompetensi digital, kreativitas, dan keterlibatan mahasiswa. Penelitian ini bertujuan untuk menganalisis efektivitas model Pembelajaran Berbasis Proyek (PjBL) yang terintegrasi dengan Kecerdasan Buatan (AI) dalam meningkatkan literasi kewirausahaan digital (DEL) dan keterlibatan belajar (LE) di kalangan mahasiswa program studi ekonomi. Penelitian ini menggunakan desain penelitian tindakan kelas dua siklus yang melibatkan 28 mahasiswa semester tiga yang terdaftar dalam mata kuliah Mikroekonomi di Universitas Nusantara PGRI Kediri. Data dikumpulkan menggunakan enam instrumen: Skala Literasi Kewirausahaan Digital, Skala Keterlibatan Belajar, rubrik proyek, lembar observasi, log aktivitas digital, dan wawancara reflektif. Analisis kuantitatif mencakup uji-t sampel berpasangan, N-gain, dan korelasi Pearson, sedangkan data kualitatif dianalisis secara tematis. Hasil penelitian menunjukkan peningkatan yang signifikan pada skor DEL dan LE setelah penerapan model PjBL yang terintegrasi dengan AI. Nilai rata-rata DEL meningkat dari 76,04 menjadi 102,96 (n-gain = 0,623; p < 0,001), dan nilai rata-rata LE meningkat dari 60,75 menjadi 79,75 (n-gain = 0,661; p < 0,001). Pengamatan dan catatan aktivitas digital menunjukkan peningkatan keterlibatan perilaku dan kognitif selama proses pembelajaran. Temuan kualitatif menunjukkan bahwa siswa memanfaatkan alat AI seperti ChatGPT, Google Sheets AI, Gemini, dan Canva AI untuk riset pasar, simulasi elastisitas harga, dan desain konten digital dengan cara yang kreatif dan etis. Studi ini menyimpulkan bahwa mengintegrasikan AI ke dalam kerangka kerja PjBL secara efektif meningkatkan literasi kewirausahaan digital siswa, menumbuhkan keterlibatan reflektif, dan mendukung pengembangan pembelajar yang adaptif, etis, dan inovatif dalam pendidikan ekonomi.

Kata Kunci: Pembelajaran Berbasis Proyek; Kecerdasan Buatan; Literasi Kewirausahaan Digital; Keterlibatan Belajar; Pendidikan Ekonomi

Implementation of Artificial Intelligence–Integrated Project-Based Learning to Enhance Digital Entrepreneurship Literacy and Student Engagement in Economics Education

Abstract

The rapid advancement of digital technology and artificial intelligence (AI) has significantly influenced higher education practices, demanding innovative pedagogical models that foster students' digital competence, creativity, and engagement. This study aimed to analyze the effectiveness of an Artificial Intelligence (AI)-integrated Project-Based Learning (PjBL) model in improving digital entrepreneurship literacy (DEL) and learning engagement (LE) among students in economics education. This study employed a two-cycle classroom action research design involving 28 third-semester students enrolled in the Microeconomics course at Universitas Nusantara PGRI Kediri. Data were collected using six instruments: the Digital Entrepreneurship Literacy Scale, the Learning Engagement Scale, the project rubric, the observation sheet, the digital activity log, and reflective interviews. Quantitative analyses included paired-samples t-tests, N-gain, and Pearson correlations, while qualitative data were analyzed thematically. The *results showed a significant improvement in both DEL and LE following implementation of the AI-integrated PjBL model. The mean DEL score increased from 76.04 to 102.96 (n-gain = 0.623; p < 0.001), and the mean LE score increased from 60.75 to 79.75 (n-gain = 0.661; p < 0.001). Observations and digital activity logs revealed higher behavioral and cognitive engagement during the learning process. Qualitative findings indicated that students utilized AI tools such as ChatGPT, Google Sheets AI, Gemini, and Canva AI for market research, price elasticity simulations, and digital content design in creative and ethical ways. The study concludes that integrating AI into the PjBL framework effectively enhances students' digital entrepreneurship literacy, fosters reflective engagement, and supports the development of adaptive, ethical, and innovative learners in economic education.*

Keywords: *Project-Based Learning; Artificial Intelligence; Entrepreneurship Literacy; Learning Engagement; Economics Education*

1. Introduction

The integration of digital technology and artificial intelligence (AI) into higher education has reshaped pedagogical practices, requiring a transformation from traditional teacher-centered learning to student-centered, technology-enhanced learning environments (Langat, 2024). In economics education, particularly in microeconomics courses, instruction still tends to emphasize theoretical explanations over practical applications supported by data and digital tools (Munárriz & Rincón, 2025). Consequently, students often struggle to relate economic concepts, such as elasticity, market structure, and price mechanisms, to real-world entrepreneurial contexts. These learning limitations have led to low digital literacy, weak analytical reasoning, and a lack of innovation in the use of technology for entrepreneurial activities among students (Rahmi et al., 2025).

Digital entrepreneurship literacy (DEL) has emerged as an essential competence in the digital economy, where students are expected to integrate entrepreneurial thinking with digital proficiency (Zapata et al., 2024). Digital literacy (DEL) refers to the ability to use digital platforms to identify opportunities, process data, communicate value, and manage ethical digital behavior (Tasrif et al., 2024). In economics education, this literacy is fundamental to preparing graduates who can transform theoretical understanding into practical entrepreneurial action supported by digital ecosystems (Suratno et al., 2021). However, studies in the Indonesian context indicate that students' digital literacy and readiness to engage with artificial intelligence remain limited, particularly in terms of applying these technologies for learning and innovation (Zaki et al., 2024).

To address these challenges, universities must implement instructional models that enhance students' cognitive mastery and cultivate technological adaptability, creativity, and ethical awareness. Project-Based Learning (PjBL) offers a relevant pedagogical approach because it allows students to engage in collaborative projects, solve authentic problems, and produce tangible outcomes as part of the learning process (Fadli et al., 2024) (Hariyono, 2024). PjBL promotes experiential and reflective learning through the stages of problem identification, project design, implementation, evaluation, and presentation (Lathifah et al., 2025) . Previous research has demonstrated that PjBL enhances motivation, critical thinking, collaboration, and problem-solving skills across various disciplines (Hidayat et al., 2024). However, conventional PjBL implementations often rely solely on human facilitation and lack the technological support that could optimize efficiency, engagement, and creativity (Suyantiningsih et al., 2023).

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The integration of artificial intelligence into PjBL represents an important pedagogical innovation that addresses these issues. AI tools such as ChatGPT, Google Sheets AI, Gemini, and Canva AI can function as intelligent assistants, providing real-time data analysis, idea generation, feedback, and visualization support for student projects (Huamani-Anco & Maraza-Quispe, 2025). According to connectivist learning theory, learning occurs through networks that connect humans, information, and technology (Ramadhan et al., 2025). In this sense, AI serves as a "knowledge node" that expands students' access to information and enables them to process and synthesize knowledge more effectively (Zekaj, 2023). Furthermore, constructivist and experiential learning theories explain that knowledge is actively constructed through experience, reflection, and social interaction (Ballesteros-Sola & Magomedova, 2023). By integrating AI into PjBL, students can experience meaningful learning that connects conceptual understanding with authentic, technology-supported practices (Hidayati et al., 2024).

In the context of economics education, AI-integrated PjBL provides a dynamic environment for students to explore business ideas, conduct market simulations, and analyze microeconomic data using real datasets (Ali, 2019) (Hariyono, 2023). Students can design digital marketing strategies, create cost-benefit analyses, and test elasticity scenarios using AI-supported tools. This hands-on approach bridges theoretical economic principles with applied entrepreneurship, fostering both cognitive and practical understanding (Morselli & Orzes, 2023).

Previous empirical studies have also highlighted AI's potential to enhance students' engagement and higher-order thinking. For example, Zhang et al. [19] reported that AI-assisted project learning increased students' abilities to interpret data and make evidence-based decisions. Similarly, Chen and Wang found that integrating AI and PjBL strengthened students' behavioral and cognitive engagement through real-time feedback and personalized learning experiences (Sajja et al., 2025). Despite these advantages, few studies in Indonesia have examined how AI-integrated PjBL influences both digital entrepreneurship literacy and learning engagement simultaneously, particularly in economics education (Hasan et al., 2023).

Therefore, this study was designed to analyze the implementation and effectiveness of the AI-integrated PjBL model in improving students' digital entrepreneurship literacy and learning engagement in microeconomics courses. This research addresses the following gaps: (1) limited empirical evidence on the use of AI to enhance digital entrepreneurship literacy in economics education; (2) lack of contextualized learning models that combine technology and local wisdom in entrepreneurship education; and (3) need for integrated learning frameworks that foster ethical, creative, and reflective engagement among students.

Based on these considerations, the objectives of this study are as follows:

1. Implement the AI-integrated PjBL model in economics education.
2. analyze its impact on improving digital entrepreneurship literacy; and
3. Examine its influence on students' learning engagement.

Figure 1 presents the conceptual relationship between the use of AI-integrated PjBL, enhancement of digital entrepreneurship literacy, and students' learning engagement in the economics learning context.

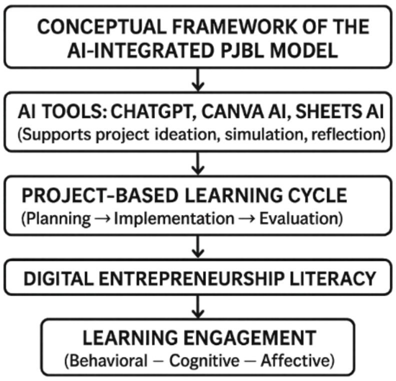

Figure 1. Conceptual Framework of the AI-Integrated PjBL Model

In summary, integrating artificial intelligence into the PjBL framework provides a novel pathway for developing economically literate, technologically proficient, and ethically aware graduates. This approach is expected to enhance the relevance of economics education in the digital era, strengthen students' entrepreneurial competencies, and contribute to sustainable, technology-driven innovations in learning in Indonesian higher education (Suparno et al., 2025).

2. Methods

This study employed a Classroom Action Research (CAR) design comprising two cycles to improve students' digital entrepreneurship literacy (DEL) and learning engagement (LE) through the implementation of an Artificial Intelligence–integrated Project-Based Learning (AI-integrated PjBL) model. The CAR design was chosen because it allows for the systematic improvement of teaching and learning practices through a process of planning, action, observation, and reflection (Kuswanto, 2020; Selimi et al., 2025). Each cycle consisted of four meetings, for a total of eight sessions over one semester of the microeconomics course.

The research was conducted at the Department of Economics Education, Faculty of Economics and Business, Universitas Nusantara PGRI Kediri during the odd semester of the 2025 academic year. The research subjects were 28 third-semester students enrolled in a microeconomics course. All students actively participated in the project-based learning process and consented to contribute their responses and reflective data for research purposes.

2.1. Research Design and Procedure

The research followed the four stages of classroom action: (1) planning, (2) implementation, (3) observation, and (4) reflection [2]. The process was iterative, with reflections from the first cycle informing revisions to the instructional strategies in the second cycle. During the planning stage, lesson plans, project rubrics, digital literacy scales,

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and engagement instruments were all prepared. AI tools, such as *ChatGPT, Google Sheets AI, Gemini,* and *Canva AI*, were integrated into each project phase to support data collection, visualization, and content design.

During the implementation stage, students were divided into seven groups, each assigned to design a project related to local economic products (Tenun Ikat, Tahu Takwa, Bawang Merah, and Kopi Kediri). They used AI to analyze market trends, simulate demand and elasticity, and design digital marketing strategies. The observation stage involved monitoring student activities using observation sheets and digital activity logs. The reflection stage focused on evaluating the project outcomes and revising the learning designs for the following cycle.

Table 1. Research Design Structure

Cycle	Meeting	Main Activities	AI Tools Used	Focused Output
I	1–4	Introduction to AI tools, project planning, and initial data gathering	ChatGPT, Sheets AI	Project draft and dataset
II	5–8	Project execution, digital content creation, evaluation, and reflection	Canva AI, Gemini, ChatGPT	Final project report and presentation

2.2. Research Instruments

Six research instruments were employed to collect quantitative and qualitative data.

a. The Digital Entrepreneurship Literacy (DEL) scale consists of 24 indicators measuring knowledge, attitude, and ethical awareness.
b. The Learning Engagement (LE) scale consists of 18 indicators across the behavioral, cognitive, and emotional domains.
c. a Project Rubric assessing creativity, collaboration, use of AI, accuracy of economic analysis, and quality of digital output;
d. an Observation Sheet used by two observers to record students' participation and engagement levels during class
e. a Digital Activity Log that automatically tracked students' frequency and duration of interactions within AI-based tools and Google Classroom; and
f. A Reflective Interview Guide to capture students' perceptions, challenges, and experiences with AI-integrated project learning (Ruiz Viruel et al., 2025; H. Zhang et al., 2024).

Each instrument was validated by two expert reviewers from the Economics Education Department to ensure content validity and relevance to the course objectives. The reliability test using Cronbach's alpha yielded values above 0.80 for both the DEL and LE scales, indicating strong internal consistency.

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2.3. Data Collection and Analysis

Data were collected in three stages: pretest, learning implementation, and posttest. Pretest data were collected to assess students' baseline DEL and LE levels before implementation of the AI-integrated PjBL model. Observation, log, and reflection data were gathered throughout the learning activities in both cycles. Posttest data were used to evaluate improvements after the second cycle.

Quantitative data were analyzed using descriptive statistics, *paired-samples t-tests, N-Gain, and Pearson correlation to assess* the significance of changes and the relationship between DEL and LE (Belmonte & Lira, 2023; Houjeir et al., 2023). Qualitative data from interviews and reflections were analyzed thematically to triangulate the quantitative findings, particularly regarding students' attitudes toward AI-assisted learning and its perceived impact on engagement and entrepreneurship skills [30]

2.4. Ethical Considerations

All participants were informed of the study's purpose, and their voluntary participation was secured through written consent. No personal identifiers were recorded. This study adhered to the research ethics guidelines of Universitas Nusantara PGRI Kediri, emphasizing data confidentiality, academic integrity, and the responsible use of AI tools in educational contexts.

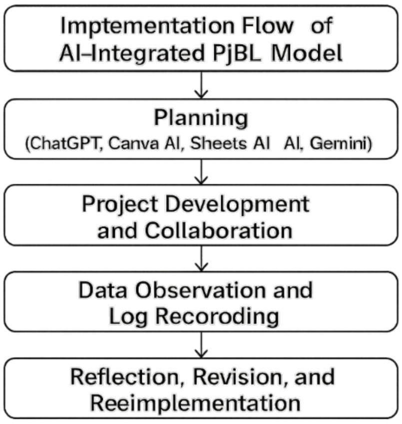

Figure 2. Implementation Flow of AI-Integrated PjBL Model

Through this structured approach, the research design ensured the rigorous implementation of the AI-integrated PjBL model, enabling a comprehensive evaluation of its impact on students' digital entrepreneurship literacy and learning engagement. The combination of quantitative and qualitative analyses strengthened the credibility of the findings, supporting a holistic understanding of how artificial intelligence can transform pedagogical innovation in economics education.

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Tabel 1. Content Representation Qestions

CoRe Questions	Essential Concept 1	Essential Concept 2
1. What will you teach students about this concept? 2. Why is this concept important for students to learn? 3. Which related ideas/concepts do you consider not yet appropriate for students at this level? 4. What difficulties do you experience in teaching this concept? 5. What student characteristics or contexts do you take into account when teaching this concept? 6. What factors do you consider in deciding how to teach this concept? 7. What instructional sequence do you choose for teaching this concept? 8. How do you determine whether students have understood the concept or not?		

3. Results

The implementation of the Artificial Intelligence (AI)– integrated Project-Based Learning (PjBL) model in the Microeconomics course was conducted in two cycles, involving 28 third-semester students in the Economics Education Study Program. Each cycle consisted of four meetings covering the stages of project planning, AI-assisted data analysis, project execution, reflection, and evaluation. Data were collected from pre- and posttest scores of the Digital Entrepreneurship Literacy (DEL) and Learning Engagement (LE) scales, as well as observation sheets, project rubrics, digital activity logs, and reflective interviews.

The results indicate that the integration of AI into PjBL significantly improved both DEL and LE, as evidenced by the quantitative and qualitative data analyses. This section presents the statistical findings, trends, and supporting evidence, using tables and figures.

3.1. Descriptive Statistics of Digital Entrepreneurship Literacy (DEL) and Learning Engagement (LE)

Table 2 summarizes the descriptive statistics of the DEL and LE scores before and after the implementation of AI-integrated PjBL.

Table 2. Descriptive Statistics of DEL and LE Scores (N = 28)

Variable	Minimum	Maximum	Mean Pretest	Mean Posttest	SD Pre	SD Post	Mean Difference
Digital Entrepreneurship Literacy (DEL)	64	89	76.04	102.96	6.24	5.69	26.92
Learning Engagement (LE)	51	70	60.75	79.75	4.68	3.82	19.00

The data showed a consistent increase in both DEL and LE scores after two cycles of implementation. The average DEL score improved by 26.92 points (35.4%), and the LE score increased by 19.00 points (31.3%). The reduction in the standard deviation values suggests a more uniform improvement across students, indicating that the AI-integrated PjBL model benefited participants at varying levels of prior competence.

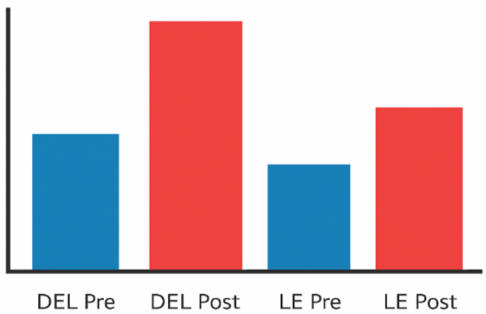

Figure 3 presents the pre- and posttest mean scores for DEL and LE.

The figure shows that both indicators increased substantially after the integration of AI tools into project-based learning cycles.

3.2. Normality Test Results

Before performing inferential tests, the normality of the DEL and LE data distributions was assessed using the Shapiro–Wilk test.

Table 3. Normality Test Results (Shapiro–Wilk)

Variable	Statistic (Pretest)	Sig.	Statistic (Posttest)	Sig.	Description
DEL	0.954	0.218	0.963	0.310	Normal
LE	0.959	0.276	0.967	0.348	Normal

Because the p-values for all variables exceeded 0.05, it was concluded that both DEL and LE data were normally distributed, justifying the use of paired-samples *t-tests*.

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3.2.1. Results of the Paired Samples t-Test

Table 4 presents the results of the *paired-samples t-test to determine whether the observed differences between* pre- and posttest means were statistically significant.

Table 4. Paired Samples t-Test Results

Variable	Mean Difference	t	df	Sig. (2-tailed)	Interpretation
DEL	26.92	14.37	27	0.000	Significant increase
LE	19.00	16.12	27	0.000	Significant increase

The results indicated statistically significant improvements in both DEL and LE ($p < 0.001$). The large *t-values and low p-values* confirm the effectiveness of the AI-integrated PjBL model in enhancing students' digital entrepreneurship literacy and learning engagement.

3.2.2. Effectiveness Analysis Using N-Gain and Effect Size

To further evaluate the effectiveness of the learning intervention, the normalized gain (N-Gain) and Cohen's *d* were calculated.

Table 5. Effectiveness Analysis Results

Variable	Mean Pretest	Mean Posttest	N-Gain	Category	Cohen's *d*	Effect Size Interpretation
DEL	76.04	102.96	0.623	Moderate–High	0.74	Strong effect
LE	60.75	79.75	0.661	High	0.82	Powerful effect

The analysis revealed N-Gain scores of 0.623 for DEL and 0.661 for LE, both exceeding the threshold of 0.6, indicating a moderate-to-large improvement. Furthermore, *the effect sizes (Cohen's d > 0.70) indicate* that the learning intervention had a strong and meaningful impact on students' performance and engagement.

Figure 4 illustrates the comparative increases in the DEL and LE scores, expressed as normalized gain percentages.

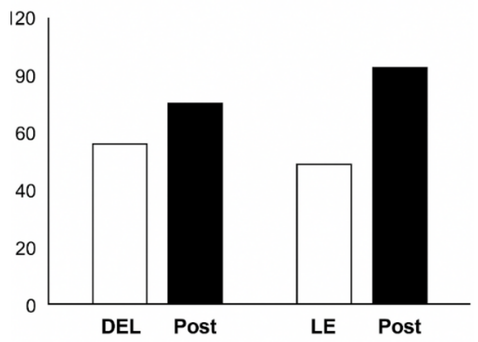

Figure 4. N-Gain Comparison between DEL and LE

The figure confirms that both indicators exhibited parallel improvement trends, with the LE achieving a slightly higher normalized gain than DEL.

3.2.3. Observation and Digital Activity Log Results

Observational data indicated a consistent increase in students' active participation and collaboration across the two learning cycles. Table 6 summarizes the results of classroom observations, digital activity logs, and project rubric assessments.

Table 6. Observation, Digital Log, and Project Performance Summary

Indicator	Cycle I	Cycle II	Improvement (%)	Performance Level
Classroom Engagement Score (0–18)	10.12	14.39	+42.2%	High
Digital Activity Log (0–25)	11.23	13.91	+23.8%	Good
Project Rubric Score (1–4)	2.98	3.26	+9.4%	Good–Very Good

The data show steady progress across all indicators. In Cycle I, students were still adapting to AI tools and group project coordination, whereas in Cycle II, their engagement and project quality increased considerably.

Figure 5 shows the trend in the mean observation scores across the eight meetings, indicating continuous improvement in classroom engagement.

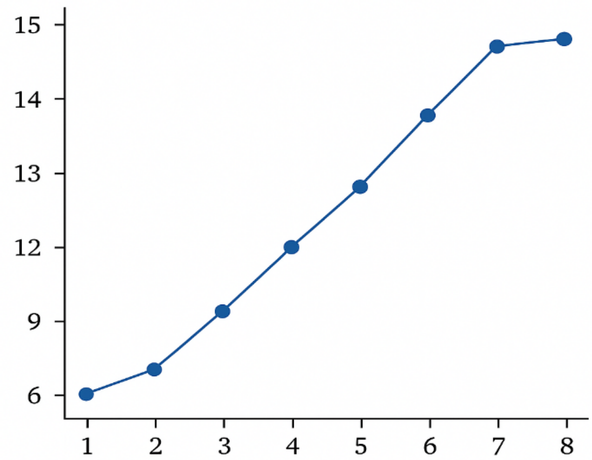

Figure 5. Trend of Mean Observation Scores across Meetings

The figure shows that the mean score of classroom engagement increased gradually from 10.3 at the first meeting to 14.6 at the eighth meeting, indicating increased behavioral and collaborative participation by the students.

3.2.4. Correlation between DEL and LE

To explore the relationship between DEL and LE improvement, Pearson's correlation analysis was conducted on posttest data from 28 students.

Table 7. Correlation between DEL and LE

Variable Pair	Correlation Coefficient (r)	Sig. (2-tailed)	Interpretation
ΔDEL – ΔLE	0.68	0.000	Strong Positive Relationship

The correlation coefficient of r = 0.68 ($p < 0.001$) indicates a strong positive relationship between students' improvement in digital entrepreneurship literacy and their learning engagement. This implies that students with higher levels of digital literacy tend to demonstrate greater engagement, motivation, and collaboration in the learning process. Figure 6 illustrates this relationship using a scatter plot of the data.

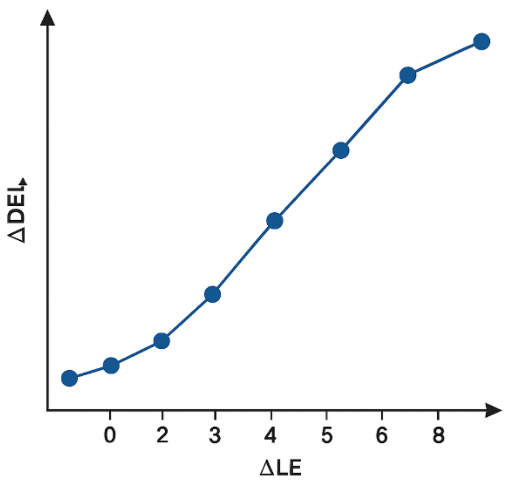

Figure 6. Scatter Plot of DEL and LE Improvements

The scatter plot shows a clear upward trend, with most data points clustering in the upper-right quadrant, indicating that improvements in DEL are closely associated with increased engagement.

3.2.5. Qualitative Findings

Qualitative data from interviews and reflections supported these quantitative results. Four key themes emerged.

a. AI as a learning companion: Students used AI to generate ideas, clarify concepts, and verify economic data.
b. Enhanced digital creativity: AI helped students produce professional-quality project outputs, such as promotional designs, infographics, and simulation dashboards.
c. Collaborative reflection: Team-based projects using AI platforms encourage peer learning and responsibility sharing.
d. Ethical awareness: Students became more mindful of transparency and acknowledgment when using AI tools for academic work.

Representative student reflections include the following:

"AI helped me simulate market elasticity and visualize data better. I learned how to use technology ethically and creatively."

These qualitative findings confirm that AI-integrated PjBL not only improved measurable learning outcomes but also fostered ethical and reflective learning behaviors.

3.2.6. Summary of Key Results

The findings demonstrate that the implementation of AI-integrated PjBL effectively enhanced both digital entrepreneurship literacy and student learning engagement. The significant improvement across all data sources (quantitative, observational, and qualitative) validates the model's pedagogical potential.

Table 8. Summary of Key Results

Aspect	Result Summary	Category / Interpretation
Digital Entrepreneurship Literacy	Increased from 76.04 → 102.96 ($p < 0.001$)	Significant Improvement
Learning Engagement	Increased from 60.75 → 79.75 ($p < 0.001$)	Significant Improvement
Normality & t-Test	Data normally distributed; t-values significant	Reliable Results
N-Gain & Effect Size	0.62–0.66; Cohen's d 0.74–0.82	Strong Effect
Correlation (DEL–LE)	$r = 0.68$, $p < 0.001$	Strong Positive Relationship
Observation & Activity Logs	+42% Engagement Increase	Highly Active
Project Quality	Improved by 9.4%	Good–Very Good

Overall, these results confirm that integrating AI into project-based learning not only strengthens students' understanding of economic concepts but also enhances their digital entrepreneurship competence and engagement in active, reflective, and ethical learning processes.

4. Discussions

4.1. Students understanding about global warming

Building on the "medium–tending-to-low" profile captured by CoRe, the principal implication is to reframe the evaluation of global-warming understanding for pre-service science teachers toward conceptual evidence rather than definitional recall. The CoRe outputs make visible persistent weaknesses on items that demand mechanistic reasoning—for example, articulating the radiation–absorption–re-radiation relations and differentiating natural greenhouse effects from anthropogenic global warming—as well as on specifying clear indicators of attainment. Accordingly, evaluation should incorporate claim–evidence–reasoning tasks using authentic data (e.g., anomaly temperature graphs, atmospheric CO_2 concentrations, sectoral emissions), supported by performance rubrics that explicitly probe conceptual accuracy, mechanistic justification, and transfer to local contexts. These recommendations are consistent with literature indicating that CoRe is

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effective in surfacing content–pedagogy gaps and guiding the design of more meaningful assessments (Sannert et al., 2025; Yanti et al., 2020).

Compared with prior studies on pre-service science teachers, our findings align with the broader tendency for content mastery to plateau at a medium level (Chan, 2023). Earlier research also notes that respondents readily state “what to teach” and “why it matters,” yet struggle when asked to elaborate coherent conceptual sequencing and specific indicators of understanding. The distinctive feature of our results is the sharper shortfall on evidence-based reasoning, particularly in formulating indicators of understanding and justifying instructional sequences both clustering at mid-to-lower performance levels. This contrasts with some reports that describe more even gains in assessment planning; in our context, conceptual assessment literacy and sustained use of evidence appear not yet habitual.

The still-generic descriptions of student context indicate that the knowledge of students' understanding component of PCK encompassing awareness of preconceptions, common misconceptions, variation in readiness to learn, and language/representational barriers—has not yet been fully internalized as a basis for instructional decision-making. Consequently, knowledge of instructional strategies also appears underdeveloped: conceptual sequencing and the choice of approaches remain largely generic because they are not derived from a specific learner profile (e.g., differentiating strategies for students with low versus high data literacy, or using multimodal representations to bridge particular misconceptions).

Fragility in these two components then resonates into knowledge of assessment within PCK: success indicators tend to be global and are not designed to capture shifts in understanding that are meaningful for actual learners (for instance, indicators that trace the reduction of greenhouse-effect misconceptions or the ability to interpret locally sourced graphs). Thus, the medium–tending-to-low outcomes on the “student context” and “decision factors” items are not merely matters of incomplete responses; they signal that the bridge across PCK components—from recognizing learner characteristics, to selecting fit-for-purpose strategies, to designing aligned assessments—has not been firmly constructed. Going forward, CoRe can serve as a scaffolding vehicle to link these three components explicitly: each statement about student context should be followed by a strategic consequence in the instructional design and an observable assessment indicator, so that PCK develops not only as declarative knowledge but as an operational pedagogical rationale in practice.

A plausible explanation for this profile relates to the respondents' status as pre-service teachers at an early stage of their professional trajectory. Their opportunities for teaching practice and engagement with empirical classroom data are likely limited; as a result, their “why” and “how” arguments—especially on items requiring evidence and measurable indicators—tend to be declarative rather than analytic. In addition, the habit of designing conceptual sequences that integrate phenomena model data application appears to be underdeveloped in microteaching scenarios, yielding linear, definition-centered progressions.

Within the global-warming topic, the findings also point to persistent, characteristic misconceptions among pre-service/early-career teachers—for example, equating the greenhouse effect with global warming or conflating ozone issues. Without early diagnosis, such misconceptions easily carry over into classroom practice and shape choices of sequencing and examples (Hanke & Schmalor, 2025; Pardo et al., 2024). Accordingly, the student context → strategy → assessment chain needs to be strengthened through CoRe-based scaffolding that prompts pre-service teachers to articulate strategic consequences for every piece of information about learners, while simultaneously developing specific, evidence-informed indicators of understanding (Sannert et al., 2025)

4.2. Implications for Education Curricula

Implikasi langsung bagi pengembangan kurikulum di program kependidikan adalah perlunya Two areas of strengthening are recommended. First, deepening content through mechanisms by sharpening interconcept linkages and guiding students to construct explicit maps of essential concepts. Second, assessment for conceptual understanding through the routine use of specific success indicators, data-driven analytic tasks, and structured feedback. The integration of evidence-based activities—for example, interpreting trend graphs, analyzing local case studies, and engaging in claim–evidence–reasoning—should become a regular feature of both content and pedagogy courses so that students habitually connect concepts to data and context (Nilsson & Karlsson, 2018; Schultze et al., 2018).

For pedagogical competence development, these findings call for a refinement of microteaching that evaluates not only presentation performance but also the quality of conceptual sequencing and the rationale for assessment (Dragnić-Cindrić & Anderson, 2025). Microteaching scenarios should be engineered to surface difficult instructional decisions—such as selecting prerequisite concepts, timing the introduction of counterexamples, or probing characteristic misconceptions so that pre-service teachers must articulate the reasons behind their choices. This approach is strengthened by CoRe-based rubric feedback, enabling students to see a direct link between the quality of their reflective responses and the instructional designs they will enact in practice.

Substantively, the results corroborate the study's hypothesis: participants' understanding sits at a medium, tending-to-low level, with clear weaknesses in depth of reasoning, in establishing coherent conceptual sequences, and in formulating evidence-based indicators of understanding. The findings align with prior work in the prevalence of declarative responses and a tendency toward linear sequencing; they differ in our context by showing weaker evidential argumentation; and they are distinctive in the contrast between the ability to list concepts and the ability to operationalize assessment of understanding (Behling et al., 2025; Konadu & Student, 2025)

The broader implication for the field is the need to bridge content knowledge and assessment literacy early in teacher preparation. When pre-service teachers are habituated to interrogate data, test conceptual claims, and articulate clear success indicators, they not only understand the ideas but also learn how to verify students' understanding. Over time, this shift can enrich science teaching in schools by making pedagogical decisions more transparent, measurable, and locally relevant.

This study has limitations. The small, single-institution sample constrains generalizability. The data were collected through reflective CoRe responses and therefore depend heavily on respondents' written articulation; without classroom observations or instructional artefacts, some aspects of practice may be underrepresented. In addition, although rater agreement was supported by a rubric, scorer bias remains possible. These limitations motivate follow-up studies with more diverse samples, triangulation via observation and product analysis, and stronger procedures to enhance scoring reliability.

5. Discussion

The findings of this study confirm that the integration of Artificial Intelligence (AI)-based Project-Based Learning (AI-integrated PBL) has a significant and positive effect on improving Digital Entrepreneurship Literacy (DEL) and Learning Engagement (LE) among economics education students. The results not only validate the quantitative improvements but also demonstrate how AI integration transforms students' learning experiences cognitively, behaviorally, and affectively (Buchner et al., 2021; Y. Zhang & Miao, 2025). This section discusses the findings in relation to existing theories and prior studies and their implications for future educational practice.

5.1. The Impact of AI-Integrated PjBL on Digital Entrepreneurship Literacy

The increase in DEL from 76.04 to 102.96 with an N-Gain of 0.623 and a strong effect size (Cohen's d = 0.74) demonstrated that the AI-integrated PjBL model effectively enhanced students' digital entrepreneurial competencies. These results support previous findings that project-based learning strengthens applied knowledge and creative problem-solving abilities when combined with technology-assisted scaffolding (Koong Lin et al., 2025).

According to the constructivist learning theory, learners actively construct their knowledge through experience and reflection (Amanbaikyzy & Jakavonytė-Staškuvienė, 2025; Heimbûrger et al., 2020). The integration of AI provides students with immediate feedback and relevant data for analysis, thereby supporting higher-order cognitive processing and autonomous decision-making. Students' use of ChatGPT for problem clarification, Google Sheets AI for data analysis, and Canva AI for digital marketing simulations allowed them to engage directly with entrepreneurial contexts. This process mirrors Kolb's experiential learning stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation.

In addition, AI tools support contextualized learning, enabling students to connect microeconomic theory to real-world market phenomena. For example, groups using AI for elasticity and price simulations can visualize demand–supply relationships in real time. This finding aligns with earlier studies that emphasize how AI enhances data literacy, analytical reasoning, and contextual understanding in economics education (Carmel-Gilfilen & Portillo, 2010).

From a digital entrepreneurship perspective, the PjBL model cultivates essential 21st-century entrepreneurial literacies, including opportunity recognition, digital innovation, and ethical use of technology (Suanpong et al., 2025). Qualitative reflections from students also revealed growth in their confidence to integrate AI responsibly into entrepreneurial practices. These findings align with Ng's definition of digital entrepreneurship literacy, which encompasses not only mastery of digital tools but also the ethical, social, and cognitive dimensions of technology use for business innovation (Ta'Amnha et al., 2024).

5.2. Enhancement of Learning Engagement through AI-Supported Collaboration

The results indicate that students' learning engagement increased substantially (from 60.75 to 79.75, N-gain = 0.661, Cohen's d = 0.82). These findings confirm that AI-integrated PjBL promotes active, collaborative, and reflective engagement (Ou & Joyner, 2025). The behavioral aspect of engagement was evident in higher attendance, participation, and project submission rates; cognitive engagement was reflected in problem-solving and analytical discussions; and emotional engagement was reflected in students' enthusiasm and satisfaction with the use of AI tools.

This aligns with the Self-Determination Theory proposed by Deci and Ryan, which posits that motivation and engagement are driven by the fulfillment of autonomy, competence, and relatedness (Sanabria-Navarro et al., 2023). The AI-integrated PjBL model addressed all three elements: students had autonomy in designing their projects, competence was enhanced through AI-guided data analysis, and the sense of relatedness was strengthened via group collaboration.

Moreover, the concept of connectivism explains that learning in the digital age occurs through interconnected systems of people, data, and technology (Dziubaniuk et al., 2023). AI tools act as mediators of knowledge construction, enabling students to access a broader range of information, engage in networked collaboration, and receive instant feedback. This networked learning environment enhances students' sense of engagement and ownership (Dym et al., 2023).

Observational data and digital activity logs support this interpretation, showing a 42% increase in active classroom participation and a 23.8% increase in digital engagement across the two cycles. These improvements align with Chen et al.'s research, which highlighted that AI-supported PjBL environments significantly enhance student engagement through adaptive feedback and interactive task design (Jylhä & Hamari, 2020).

Furthermore, the qualitative findings illustrated that AI inspired students to experiment with ideas, share insights, and learn from mistakes in a psychologically safe, digital space. These patterns are consistent with Garrison and Cleveland-Innes's Community of Inquiry framework, which identifies cognitive, social, and teaching presence as foundational elements of meaningful online learning (Steel, 2023). The AI-integrated PjBL model enhanced all three presences: cognitive presence through data analysis, social presence through collaborative teamwork, and teaching presence through instructor facilitation of AI ethics and inquiry.

5.3. Relationship between Digital Literacy and Learning Engagement

Correlation analysis revealed a strong positive association ($r = 0.68$, $p < 0.001$) between DEL and LE, indicating that higher digital literacy was associated with greater engagement. This finding aligns with prior research indicating that digital competence is a key predictor of students' engagement and academic success in technology-rich learning environments (Chugh et al., 2023).

Students who effectively managed AI tools became more confident and autonomous learners, which, in turn, increased their persistence and participation in learning activities. This finding reflects the synergy between technological self-efficacy and academic engagement, suggesting that equipping students with digital skills directly contributes to (Lövdén et al., 2020).

From a pedagogical perspective, this relationship indicates that DEL and LE are mutually reinforcing constructs within the AI-integrated PjBL ecosystem. The more students understand how to leverage technology for learning and problem solving, the more actively they engage with content and peers. Such an interplay also aligns with the theory of Technology-Enhanced Learning (TEL), which posits that technology integration amplifies engagement when it is pedagogically aligned with authentic learning goals (Goode et al., 2022).

5.4. Integration of AI in Project-Based Learning: A Pedagogical Transformation

The inclusion of artificial intelligence in PjBL not only provided technical assistance but also redefined the roles of learners and instructors. AI serves as a co-facilitator, offering personalized feedback, generating creative alternatives, and visualizing data patterns that would otherwise be inaccessible to students (Vidergor & Academic, 2022). This transformation aligns with the principles of 21st-century pedagogy, which emphasize collaboration, creativity, communication, and critical thinking (the 4Cs) (Jing et al., 2023).

Through this model, students became active knowledge constructors, rather than passive recipients of information. The lecturer's role shifted toward that of a designer of learning experiences and a guide to the ethical use of AI. The inclusion of ethical reflection through the "AI Disclosure Box" encouraged students to cite AI contributions transparently, fostering integrity and academic honesty in their work.

These outcomes are consistent with research emphasizing that AI-supported PjBL enhances metacognitive awareness and reflective learning (Clarke & Boud, 2016). Students were encouraged to evaluate AI outputs critically, detect algorithmic bias, and make reasoned judgments about the validity of the information. As a result, they developed higher levels of digital citizenship and technological ethics skills, which are essential for entrepreneurial and professional success in the digital era (Lemieux et al., 2023).

Moreover, the contextual integration of Kediri's local wisdom (e.g., Tenun Ikat, Tahu Takwa, Bawang Merah) strengthened the relevance and sustainability of learning. By aligning global AI technology with local economic contexts, students gained an appreciation of how innovation and culture coexist in regional entrepreneurship. This aligns with the principles of Education for Sustainable Development (ESD), which encourages culturally responsive and community-oriented innovation (Kaffenberger et al., 2023).

5.5. Implications and Future Perspectives

The successful implementation of AI-integrated PjBL has several pedagogical implications for teacher education. First, it demonstrates that AI can serve as an effective learning partner, rather than a replacement for teachers. By providing adaptive scaffolding, AI helps students engage in higher-order thinking and creative production, thereby enriching the learning ecosystem (Munshi et al., 2022).

Second, this model supports the development of hybrid learning frameworks that combine face-to-face collaboration with AI-based digital interactions. The synergy between human and artificial intelligence can be further optimized through institutional support, such as AI literacy training for lecturers and students alike.

Third, this study underscores the importance of ethical awareness and transparency in the use of AI in academic settings. The inclusion of reflective components in project assessments ensures that students critically evaluate the technological influences on their learning outcomes.

Nevertheless, this study has certain limitations. The relatively small sample size (n = 28) and single-institution context limit the generalizability of the findings. Future studies should replicate this research with larger samples, different disciplines, or longitudinal designs to examine the sustainability of the effects of AI-integrated learning. In addition, further investigation of the mediating roles of entrepreneurial self-efficacy and digital creativity within the AI-integrated PjBL model would yield more profound insights into the mechanisms of learning transformation (Hu & Zheng, 2023).

5.6. Synthesis

Overall, the discussion highlights that AI-integrated PjBL has a multidimensional impact: it enhances digital literacy, fosters engagement, cultivates ethical awareness, and bridges the gap between theoretical and practical knowledge in economics education. The findings affirm that technology, when combined with project-based pedagogy, not only improves learning outcomes but also shapes students into innovative, reflective, and responsible digital entrepreneurs.

In conclusion, this study contributes to both theoretical and practical advancements in education by positioning the AI-integrated PjBL model as a transformative and sustainable framework for integrating technology, entrepreneurship, and local wisdom in higher education.

6. Conclusion

This study concludes that the Artificial Intelligence (AI)– integrated Project-Based Learning (PjBL) model is a practical pedagogical framework for improving both Digital Entrepreneurship Literacy (DEL) and Learning Engagement (LE) among students in economics education. Implemented through two classroom action research cycles involving 28 third-semester students, the model successfully transformed traditional microeconomics learning into an interactive, data-driven, and ethically reflective process.

Quantitative analysis showed significant improvements in students' literacy and engagement. The mean DEL score increased from 76.04 to 102.96, while the LE score increased from 60.75 to 79.75, both with $p < 0.001$ and strong effect sizes. These gains were further supported by normalized gain scores (0.62–0.66), confirming the model's moderate to high effectiveness. Observation and activity log data indicated a 42% increase in classroom engagement and a 23.8% improvement in digital collaboration. Simultaneously, correlation analysis ($r = 0.68$, $p < 0.001$) established a strong positive relationship between DEL and LE. The findings verify that integrating AI tools such as ChatGPT, Gemini, Google Sheets AI, and Canva AI enhances students' analytical abilities, creativity, and reflective use of technology.

Beyond statistical outcomes, qualitative reflections revealed four key transformations: (1) AI served as a cognitive partner that scaffolded critical thinking; (2) digital creativity expanded through AI-supported content design; (3) teamwork and collaborative reflection deepened students' social learning; and (4) ethical awareness in AI usage became a consistent practice. These aspects indicate that the AI-integrated PjBL model not only enhances technical competence but also cultivates integrity, empathy, and responsibility—attributes essential for sustainable entrepreneurship in the digital era.

Theoretically, this study strengthens the convergence of constructivism, connectivism, and experiential learning in technology-enhanced education. Learning becomes meaningful when students construct knowledge through interactions with both peers and intelligent systems. Practically, this study provides a scalable model that can be adapted across disciplines. Institutions are encouraged to embed AI literacy training and reflective evaluation into curriculum design, ensuring that technology use remains pedagogically grounded and ethically sound.

Nevertheless, limitations remain regarding sample size and scope. Future studies should involve larger populations, comparative groups, and longitudinal observations to assess the long-term impacts on entrepreneurial self-efficacy, innovation, and digital creativity. Further exploration of AI analytics for formative assessments could enrich the model's adaptability and sustainability.

In conclusion, the AI-integrated project-based learning model offers a transformative pathway for higher education. It aligns theoretical economics with authentic digital practice, empowers students to become innovative and ethical digital entrepreneurs, and contributes to the realization of the goals of Outcome-Based Education (OBE) and Education for Sustainable Development (ESD). By merging human and artificial intelligence reflectively and responsibly, this pedagogical innovation ensures that economics education remains relevant, future-oriented, and profoundly humanistic.

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