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Empowering Future Innovators: Harnessing Project-Based Learning and AI to Enhance Analytical Thinking, Creativity, and Collaboration Skill in Exploring the Circulatory System SMAN 1 Magelang City

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Abstract: Modern learning focuses on active student engagement through thinking, creativity, and collaboration, supported by PjBL and AI to suit the digital era. This study explores the impact of AI-assisted project-based learning (PjBL) on students' analytical thinking, creative thinking, and collaboration skills in biology education, focusing on the circulatory system. Using a quasi-experimental design with 80 eleventh-grade students (40 experimental, 40 control) from SMAN 1 Magelang, Indonesia, the research employed MANOVA and ANOVA to analyze posttest scores. Results revealed significant improvements in the experimental group, with mean differences of 5.67 (analytical thinking, *p* = 0.001), 4.12 (creative thinking, *p* = 0.010), and 3.89 (collaboration, *p* = 0.015). AI tools enhanced analytical skills through data visualization and feedback, fostered creativity via simulations and iterative problem-solving, and supported collaboration via AI-driven task allocation and communication platforms. However, collaboration gains were more modest, underscoring the enduring role of interpersonal dynamics. The study concludes that integrating AI into PjBL effectively cultivates higher-order thinking skills, though its implementation requires balancing technological and human-centric pedagogical approaches. These findings advocate for AI as a transformative tool in biology education, provided ethical and accessibility considerations are addressed.

Keywords: Analytical thinking; Artificial intelligence; Collaboration skill; Creative thinking; Project-based learning

Introduction

Education has seen tremendous changes as a result of technological advancements, especially in the area of artificial intelligence (AI) (Dignum, 2021). AI has enormous potential to improve learning outcomes, provide individualized instruction, and enhance students' educational experiences (Noroozi et al., 2024; Sucilestari et al., 2025). AI can be a useful tool in biology education to help with the difficulties of material

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abstraction and complexity, particularly when it comes to subjects like the human circulatory system that demand in-depth knowledge. It is anticipated that the use of AI-assisted project models in biology education will improve students' capacity for critical, imaginative, and cooperative thought.

Biology, as the scientific discipline focused on the study of living organisms, frequently involves complex and abstract concepts that pose significant challenges for learners (Gilissen et al., 2021). One crucial topic in biology is the human circulatory system, which requires a comprehensive understanding of the structure, function, and interactions of its components, including the heart, blood vessels, and blood (Husain-Syed et al., 2015). However, traditional pedagogical approaches—such as textual explanations and static imagery—often fall short in conveying the dynamic and multidimensional nature of these biological processes. In response to this challenge, this research introduces a novel approach by integrating Artificial Intelligence (AI) into project-based learning (PjBL) to enhance students' analytical, creative, and collaborative thinking in understanding the circulatory system (Anam et al., 2025; Darmilah et al., 2025).

The distinctive contribution of this research lies in its focused implementation of Artificial Intelligence (AI)-supported project-based learning (PjBL) models within the context of a specific and conceptually challenging biology topic—namely, the human circulatory system. Unlike general applications of AI in education, which often center on content delivery or administrative support, this study applies AI in a more targeted and interactive manner, using it as an integral part of a structured, student-centered learning strategy. While the use of AI in education has grown significantly in recent years, existing literature reveals a notable gap in studies that integrate AI technologies within the PjBL framework—particularly for the purpose of teaching complex and dynamic biological systems. This research aims to fill that gap by redefining the role of AI: not simply as a passive tool for visualization or automation, but as an active learning partner that facilitates critical scientific processes. Specifically, AI is employed to assist students in interpreting biological data, constructing scientific hypotheses, and engaging in collaborative problem-solving tasks. Through this approach, students are encouraged to take an active role in inquiry-based learning, which enhances both their conceptual understanding and higher-order thinking skills (Harry, 2023; Favero, 2024; Xu, 2024).

This research is important for several compelling reasons. First, it supports the development of essential 21st-century skills such as collaboration, creativity, and critical thinking—skills that are increasingly vital in today's educational landscape (Celik et al., 2024). Second, AI-powered PjBL allows students to take an active role in the learning process, deepening their understanding of biological concepts while enhancing their problem-solving and analytical capabilities (Gu et al., 2024). Third, in the context of rapid technological advancement, the integration of AI in education is not a trend but a necessity. It bridges the gap between traditional teaching methods and modern educational demands that emphasize engagement, higher-order thinking, and real-world application.

Moreover, as global challenges in health, environment, and biotechnology become increasingly complex, students must be equipped with both a deep understanding of biological principles and the ability to apply them innovatively (Rahioui, 2024; Koć-Januchta et al., 2022). AI provides tools that make learning more engaging, personalized, and effective, helping students evolve from passive knowledge consumers into active creators and problem-solvers.

However, despite its transformative potential, the integration of AI into biology education also raises important ethical and pedagogical considerations (Lee & Zhai, 2024). Issues such as equitable access, data privacy, and the balance between technological and human interaction must be addressed to ensure effective and sustainable implementation. Educators also need to be equipped with the necessary skills and understanding to meaningfully incorporate AI into their teaching practice.

Therefore, this research aims to explore how AI-assisted project-based learning can enhance students' analytical, creative, and collaborative thinking in biology, specifically focusing on the human circulatory system. It is expected that AI integration will help students grasp complex concepts more effectively, develop higher-order thinking skills, and prepare for global challenges. In addition, this research is also expected to provide recommendations for the effective and sustainable implementation of AI in the context of biology education.

Method

Research Method

The study employed a quasi-experimental research method using a non-equivalent posttest-only control group design. The total sample consisted of 80 students from two biology classes: a) Experimental Class (n = 40): Students received project-based learning enhanced with AI applications. b) Control Class (n = 40): Students received project-based learning without AI integration. Data were collected after the learning intervention using structured assessment instruments.

Time and Place of Research

This research was conducted at SMAN 1 Kota Magelang, a top-ranking senior high school located in Kota Magelang, Central Java, Indonesia. The study took place during the 2024/2025 academic year, involving 11th-grade biology students.

Tools and Materials

The tools and materials used in this study included: Assessment Instruments: Essay test for measuring analytical and creative thinking, adapted from the instrument developed by Ermia (2019); Observation sheet for assessing collaboration skills; Technology & Software: SPSS version 21 for statistical analysis.

Research Stages

Below is the flowchart that outlines the stages of the research:

1. Sample Selection
(80 students from SMAN 1 Kota Magelang)
↓
2. Group Assignment
(Experimental and Control Groups)
↓
3. Implementation of Learning
(PjBL with AI vs. PjBL without AI)
↓
4. Posttest Phase
- Essay Test (Analytical and Creative Thinking)
- Observation (Collaboration Skills)
↓
5. Data Collection and Scoring
↓
6. Data Analysis (MANOVA)

Figure 1. Research stages

Data Analysis

Data analysis was conducted using Multivariate Analysis of Variance (MANOVA) with the assistance of SPSS version 21. The MANOVA test was used to examine the differences in three dependent variables—analytical thinking, creative thinking, and collaboration skills—between students who participated in conventional project-based learning and those who engaged in AI-assisted PjBL. The analysis was based on posttest scores collected after the instructional intervention.

Result and Discussion

Result

The Effect of PjBL and AI to Analytical Thinking, Creative Thinking, and Collaboration

Results of the MANOVA test to see the influence of PjBL with AI on analytical thinking, creative thinking, and collaboration. Mean Difference shows the average difference between the experimental group and the control group based on the given data. For the ability of "analytical thinking," a Mean Difference of 5.67 indicates that the experimental group has an average score 5.67 points higher than the control group. Meanwhile, for "creative thinking ability," a Mean Difference of 4.12 indicates that the experimental group outperformed the control group by 4.12 points. On the variable "collaboration," a Mean Difference of 3.89 means that the experimental group has an average score 3.89 points higher than the control group.

Table 1. The Results of MANOVA

Variables	Mean Diff	Std. Error	P-value	95% CI
Analytical thinking	5.67	1.23	0.001	(3.21, 8.13)
Creative thinking	4.12	1.45	0.010	(1.22, 7.02)
Collaboration	3.89	1.34	0.015	(1.21, 6.57)

Confidence Interval (CI) provides a range of significant differences between the two groups with a 95% confidence level. For analytical thinking ability, CI [3.21, 8.13] indicates that we can be 95% confident that the actual difference between the experimental and control groups lies within the range of 3.21 to 8.13 points. In creative thinking ability, CI [1.22, 7.02] indicates that the actual difference lies within the range of 1.22 to 7.02 points. Whereas for collaboration, CI [1.21, 6.57] indicates that the actual difference between the two groups lies within the range of 1.21 to 6.57 points. This range ensures that the observed difference is not due to chance, but rather a consistent and reliable result. Thus, the combination of Mean Difference and Confidence Interval provides a comprehensive understanding of the magnitude and significance of the differences between the experimental and control groups on each dependent variable.

The Difference between the Experimental Class and the Control Class

After determining the influence of the independent variable on the dependent variable, it is necessary to ascertain whether there is a difference between the experimental class and the control class, thus a MANOVA test is required: Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root.

Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root are test statistics used to examine multivariate differences between groups in MANOVA analysis. These four statistics yield the same F value, which is 8.32, with a p-value of 0.000. This indicates that there is a significant multivariate difference between the experimental group (which uses project-based learning and AI) and the control group (which only uses project-based learning). The p-value far below 0.05 indicates that this difference did not occur by chance, but rather due to the intervention provided. Additionally, a Partial η^2 of 0.245 indicates that 24.5% of the variance in the dependent variable (analytical, creative, and collaborative thinking abilities) can be explained by the treatment differences between the two groups. This indicates that AI-based interventions have a significant effect on influencing learning outcomes.

Table 2. The Difference between the Experimental Class and the Control Class

Effect	Value	F	Hyp df	Error df	p-value	Partial n2
Pillai’s Trace	0.245	8.32	3	76	0.000	0.245
Wilk’s Lambda	0.755	8.32	3	76	0.000	0.245
Hotelling’s Trace	0.325	8.32	3	76	0.000	0.245
Roy’s Largest Root	0.325	8.32	3	76	0.000	0.245

The Effect’s Differences of Independent on Each Dependent Variables

After conducting the MANOVA test, a follow-up ANOVA test was performed for each dependent variable separately to understand the significant differences in each aspect.

Tabel 3. The Difference Effect of Independent Variables on each Dependent Variable

Variables	SS	df	MS	F	p-value	Part n2
Analytical Thinking	150.2	1	150.2	10.45	0.001	0.120
Creative Thinking	120.8	1	120.8	8.67	0.010	0.100
Collaboration	90.5	1	90.5	5.89	0.015	0.070

The results of the ANOVA test show that analytical thinking: F (1, 78) = 10.45, p = 0.001, with Partial η^2 = 0.120. This means there is a significant difference between the experimental and control groups in analytical thinking ability. The resulting effect is classified as moderate, where 12% of the variance in analytical thinking ability can be explained by the treatment difference.

Creative Thinking: F (1, 78) = 8.67, p = 0.010, with Partial η^2 = 0.100. These results indicate that the experimental group was significantly superior in creative thinking abilities compared to the control group, with an effect size that is also considered moderate (10% of the variance explained by the treatment).

Collaboration: F (1, 78) = 5.89, p = 0.015, with Partial η^2 = 0.070. Although there is a significant difference between the two groups, the effect is relatively smaller compared to the other two variables, with only 7% of the variance explained by the treatment difference. This indicates that collaboration may be more influenced by non-technical factors, such as group dynamics and interpersonal skills, which cannot be fully optimized through AI-based interventions.

Overall, these results reinforce the finding that the application of AI in project-based learning has a significant positive impact, particularly on analytical and creative thinking skills, although its effects are more limited in terms of collaboration aspects.

Discussion

Differences in Analytical Thinking Ability

The results of the MANOVA analysis indicate that there is a significant difference in analytical thinking skills between the experimental group (which used project-based learning and AI application) and the control group (which only used project-based learning). The p-value (0.001) and effect size (Partial η^2 = 0.12) indicate that the application of AI has a significant impact on improving students' analytical thinking skills (Ospankulova et al., 2025). This can be explained through AI's ability to provide structured and analytical data, as well as instant feedback that helps students analyze problems more deeply (Sasikala & Ravichandran, 2024). AI has the ability to process large amounts of data and present it in an easily understandable form, thereby helping students identify patterns and relationships between complex concepts (Bahroun et al., 2023). This allows students to see connections between various elements of information that might not be visible manually, thereby enhancing their analytical abilities. In addition, AI can also provide quick and personalized feedback, allowing students to immediately identify errors or shortcomings in their analysis and make real-time corrections. This process not only enhances students' understanding but also builds habits of critical and systematic thinking (Kamid et al., 2022; Ward et al., 2024).

Integrating AI into project-based learning provides students with access to a wider array of relevant and diverse learning materials (Perifanou & Economides, 2025), which significantly enhances their ability to engage in more thorough and comprehensive analysis. The use of AI within project-based learning not only facilitates the acquisition of knowledge but also plays a crucial role in promoting higher-order thinking skills, such as critical thinking, problem-solving, and advanced analysis, by offering specialized tools that allow students to dive deeper into their projects (Degni, 2024; Ningsih et al., 2025). For instance, AI can curate personalized learning experiences by recommending resources, such as articles, videos, or interactive simulations that are specifically tailored to the needs of individual students. This targeted approach enables students to explore complex topics more extensively and gain insights that they might not have otherwise encountered in traditional learning environments. Moreover, AI helps to streamline project management by assisting students in organizing their tasks more effectively-providing tools for scheduling, task delegation, and progress tracking (Owan et al., 2023). AI can also mad a new discipline, this organizational support allows students to focus on the intellectual and creative components of their projects, rather than getting bogged down by logistical concerns (Holmes et al., 2019). As a result, the combination of project-based learning and AI fosters a dynamic, engaging, and adaptive learning environment that not only nurtures students' analytical and critical thinking skills but also empowers them to take greater ownership of their educational journey, making the learning process more personalized, efficient, and meaningful.

AI has the potential to greatly enhance student engagement by personalizing and adapting content to suit each student's individual understanding levels, learning styles, and pace (Rana, 2025). This becomes particularly relevant in the context of project-based learning, where students are often tasked with solving complex, real-world problems that demand a flexible and adaptive approach. With AI's assistance, students are able to receive tailored support designed to meet their unique needs, such as providing additional explanations when concepts are unclear, offering specialized exercises to reinforce learning, or even suggesting strategies to overcome specific challenges they may be facing in their projects. This personalized support not only deepens the learning experience but also strengthens students' critical and analytical thinking skills, which are essential when tackling complex, multifaceted problems (Chonkaew et al., 2016). As students engage with AI-driven tools and resources, they are encouraged to think more creatively and strategically, refining their problem-solving abilities and enhancing their overall learning outcomes. Moreover, the integration of AI into project-based learning provides students with opportunities to practice digital literacy, preparing them for a future that will undoubtedly be shaped by advanced technology. Incorporating AI into project-based learning gives students the chance to develop digital literacy, which is essential for preparing them for a future where advanced technology will play a significant role. According to Thelma et al. (2024), digital literacy in education is crucial for equipping students with the skills they need to succeed in the workforce of the future. AI's role in education not only enriches the immediate learning process but also equips students with the skills and knowledge necessary to succeed in an increasingly digital and technology-driven world.

Differences in Creative Thinking Ability

Creative thinking ability also showed a significant improvement in the experimental group with a Mean Difference of 4.12 and a p-value of 0.010. The application of AI in project-based learning provides space for students to explore creative ideas through tools such as simulations, data visualization, and design aids provided by AI technology. AI can facilitate the process of creative thinking by providing innovative alternative solutions (Holmes et al., 2019; Pramesti et al., 2022; Sari et al., 2025). It can encourage students to think outside the box. AI has the ability to analyze data quickly and generate various possible solutions based on the input information. This allows students to explore various approaches and perspectives in problem-solving, thereby encouraging them to think more creatively (Arizona et al., 2025; Shahzad et al., 2025). For example, in the context of project-based learning, AI can generate various scenarios or solutions that students can use as considerations. By comparing and evaluating these options, students not only learn to choose the most effective solution but also develop the ability to think divergently and innovatively (Kwon et al., 2025; Siyamuningsih et al., 2025).

AI can also help students develop new ideas through a faster and more efficient process of iteration and experimentation. AI can provide simulation and visualization tools that allow students to test their ideas virtually before applying them in the real world. For example, in science or engineering projects, AI can be used to create predictive models or interactive simulations that allow students to see the impact of various variables without having to conduct time-consuming and costly physical experiments (Melur et al., 2025; Falsk Raza, 2023). This process not only accelerates the development of ideas but also allows students to experiment with more options, thereby increasing the likelihood of finding creative and innovative solutions (Chen et al., 2022; Wulandari et al., 2024; Yunita et al., 2025). AI can enhance student engagement in the learning process by providing personalized and adaptive feedback (Jannah et al., 2025; Sari et al., 2024). This feedback can help students identify their strengths and weaknesses in creative thinking, as well as provide suggestions for improvement. For example, if a student has difficulty generating new ideas, AI can recommend brainstorming techniques or relevant learning resources to stimulate creativity. Thus, AI not only serves as a technical aid but also as a virtual mentor that supports the development of students' creative thinking skills.

AI can help students overcome mental barriers, such as fear of failure or lack of confidence, by providing a safe and supportive learning environment (Zafar, 2024). For example, AI can create virtual simulations or scenarios where students are free to explore various ideas, test out different approaches, and make mistakes without the fear of facing negative consequences. This freedom to experiment allows students to push their boundaries and consider creative solutions that they might hesitate to try in more traditional, high-pressure settings. By removing the fear of failure, AI encourages students to take calculated risks and embrace new challenges, fostering an environment where failure is viewed as a learning opportunity rather than a setback. As students engage with AI in these simulations, they not only enhance their problem-solving and critical thinking skills but also gain confidence in their ability to tackle complex and unfamiliar situations. Ultimately, the integration of AI into the learning process helps students develop a growth mind-set, boosting their self-esteem and empowering them to face real-world challenges with greater assurance and creativity.

Differences in Collaboration Skill

The collaboration skills of students in the experimental group were also superior compared to the control group, with a Mean Difference of 3.89 and a p-value of 0.015. The application of AI in project-based learning facilitates collaboration through collaborative platforms integrated with AI technology, such as chatbots, AI-based discussion forums, and project management tools. AI can enhance collaboration by providing more effective communication tools and facilitating task allocation based on individual capability analysis (Tiwari et al., 2024; Rasmi et al., 2025). AI has the ability to analyze data about students' skills, preferences, and performance, thereby helping to assign roles in groups more fairly and efficiently. For example, in a group project, AI can identify students with specific skills, such as data analysis or presentation, and assign them to appropriate roles. This not only ensures that each group member contributes according to their expertise but also minimizes the imbalance in task distribution, which often becomes a source of conflict in collaboration (Huysken et al., 2019; Nurussalamah et al., 2025).

AI can provide actionable recommendations to enhance team interactions by identifying conflicts or imbalances in group members' contributions. AI systems are capable of monitoring group dynamics in real-time, offering insights and feedback to improve communication and foster effective cooperation (Akinnagbe, 2024). For example, if AI detects that one individual dominates the discussion while others remain passive, it can suggest redistributing speaking opportunities more equitably. This proactive approach helps mitigate tensions and ensures that all voices are heard, promoting a more inclusive and balanced dialogue (Hussein, 2021). By addressing these issues, AI not only enhances the structure of collaboration but also contributes to a harmonious and productive team environment.

AI improve student motivation and engagement in the collaborative process. AI-based collaboration platforms, for instance, can offer functions like project management software, virtual discussion boards, and automated evaluation systems that facilitate student interaction and progress monitoring. Because learners can directly see how their efforts affect the project as a whole, these elements not only increase the transparency of the cooperation process but also encourage students to participate fully. However, it is important to note that the effectiveness of AI in enhancing collaboration also depends on non-technical factors, such as group dynamics and students' interpersonal skills. Collaboration is a complex process involving aspects such as trust, communication, and conflict management, which cannot always be optimized solely through technology (Dave et al., 2023). Therefore, although AI can facilitate more structured and efficient collaboration, the role of teachers and educators remains crucial in guiding students to develop the necessary interpersonal skills.

Conclusion

This study concludes that integrating Artificial Intelligence (AI) into project-based learning (PjBL) in biology education effectively cultivates higher-order thinking skills, including analytical thinking, creative thinking, and collaboration, more significantly than traditional PjBL approaches without AI. AI supports deeper conceptual understanding by providing personalized feedback, dynamic data visualization, and interactive collaborative tools that encourage iterative experimentation and complex problem-solving. Although improvements in collaboration skills were observed, these gains were comparatively smaller, emphasizing that human interpersonal interactions remain essential in educational settings. Generalizing beyond biology education, these results suggest that AI-enhanced learning models can transform STEM education by making complex and abstract concepts more accessible, engaging, and meaningful for students. The use of AI fosters active learning environments where students develop critical 21st-century skills needed to navigate and contribute to an increasingly technology-driven world. From a practical perspective, this research highlights the necessity of balancing technological integration with human-centric pedagogical approaches to optimize learning outcomes. Educators should carefully address ethical considerations such as equitable access to AI tools and data privacy while ensuring that AI applications complement rather than replace vital teacher-student interactions. Furthermore, effective teacher training and support systems are essential for the sustainable and meaningful implementation of AI in classrooms. Overall, this study advocates for the thoughtful and deliberate incorporation of AI into biology education and beyond, positioning it as a transformative tool that prepares students to meet future scientific and technological challenges with creativity, critical thinking, and collaborative competence.

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