Journal of Educational Analytics (JEDA)
Vol. 4, No. 3, 2025: 635-646

The Effectiveness of Using Artificial Intelligence Media to Improve Students' Critical Thinking Skills in Biology Learning Concepts

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ARTICLEINFO

Keywords: Artificial Intelligence, Critical Thinking, Biology Learning, Digital Media, Higher Education

Received : 10, July
Revised: 26, July
Accepted: 27, August

ABSTRACT

This study aims to test the effectiveness of using Artificial Intelligence (AI)-based learning media in improving students' critical thinking skills in learning biological concepts, specifically the excretory system. The method used is quasi-experimental with a pre-test and post-test design on the experimental group and control group conducted in one learning cycle. The results of the study indicate that there is a significant difference between the two groups ($p < 0.05$) with a very large effect size. Thus, the integration of Artificial Intelligence (AI) can significantly improve learning outcomes and students' critical thinking skills. The implications of this study emphasize the importance of applying AI technology in biology concept learning in higher education.

DOI: https://doi.org/10.55927/jeda.v4i3.340
ISSN-E: 2830-0432
https://nblformosapublisher.org/index.php/jeda

INTRODUCTION

The development of digital technology has revolutionised the world of education, especially with the advent of artificial intelligence (AI), which has brought about changes in the way students learn and teachers teach. In the context of biology education, critical thinking skills are important skills that support students in understanding complex concepts, solving problems, and connecting scientific knowledge to real life (Papaneophytou & Nicolaou, 2025). However, the reality in the field shows that students' critical thinking skills are still relatively low, especially in learning that is still dominated by conventional methods such as lectures and memorisation (Lawasi, Rohman, & Shoreamanis, 2024; Ivanova & Petrova, 2024).

AI offers great potential in improving the quality of learning by providing interactive media, adaptive feedback, and contextual simulations that encourage reflection and self-evaluation (Kim & Zhang, 2025; Gonsalves, 2024). Some studies also indicate that AI can facilitate the development of critical thinking through the use of chatbots, adaptive learning systems, and machine learning-based data analysis (Syafriati, 2024; Ríos et al., 2025). However, the application of AI in education also raises concerns, such as technological dependence and the potential neglect of deep thinking processes (Gonsalves, 2024; Ivanova & Petrova, 2024). In the context of higher education, particularly biology education, the integration of AI-based media is considered important for preparing students to face the challenges of the digital age. Studies indicate that science education should prioritise approaches that foster higher-order thinking skills, rather than mere memorisation (Papaneophytou & Nicolaou, 2025; Nugroho & Sari, 2023). Therefore, it is important to conduct research to evaluate the effectiveness of AI-based media in improving students' critical thinking skills, especially in analytical and contextual biology learning.

This research contributes to the enrichment of scientific knowledge through the use of a quasi-experimental approach with AI-based media as a learning intervention, as well as the use of standardised critical thinking instruments to measure cognitive changes in students. The main contribution of this research lies in the integration of AI media in a unique local context, as well as the observation of students' responses and interpretations of the adaptive technology-based learning process. Based on this background, this study aims to examine the effectiveness of using AI-based media in improving students' critical thinking skills in biology learning.

THEORETICAL REVIEW

Critical Thinking Theory

Critical thinking is an intellectual ability to analyse, evaluate, and make decisions based on evidence and logic (Scriven & Paul, 1987 in Gonsalves, 2024). According to Bloom, critical thinking is included in the highest cognitive level, which encompasses analysing, evaluating, and creating. In analytical biology learning, critical thinking skills are very important so that students do not just memorise concepts, but are able to connect information and apply it in real life (Papaneophytou & Nicolaou, 2025). Previous research has shown that the use of digital technology, particularly AI-based media, can facilitate the improvement

of critical thinking skills through interactivity and adaptive feedback (Nugroho & Sari, 2023; Syafriati, 2024). However, some studies also caution that there is a potential for dependence on technology, which can reduce individual reflection if not balanced with active user involvement (Ivanova & Petrova, 2024; Ríos et al., 2025). H1: The use of AI-based media significantly improves students' critical thinking skills in biology learning.

Constructivism Theory in Learning

Constructivism emphasises that knowledge is actively constructed by students through interaction with their environment and meaningful learning experiences. AI as a learning tool can create a constructivist learning environment through simulations, virtual experiments, and tasks that encourage independent and collaborative exploration (Kim & Zhang, 2025). In the context of biology learning, AI can provide students with space to construct their own knowledge through problem solving, virtual discussions, and adaptive formative assessment (Lawasi et al., 2024; U.S. Department of Education, 2023). This technology can adapt to individual learning styles and overcome the limitations of conventional teaching methods. H2: The integration of AI media into the biology learning process creates a more interactive and reflective learning experience compared to traditional teaching methods.

Conceptual Framework Research

Here is the research:

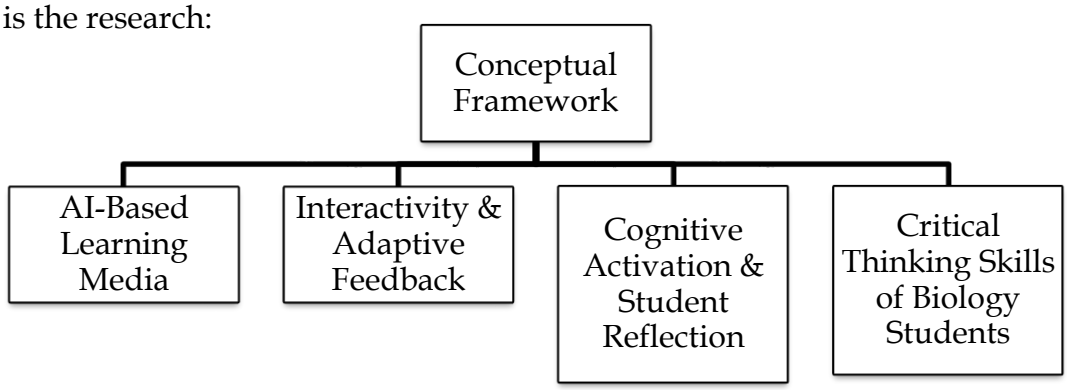

Figure 1. Conceptual Framework

METHODOLOGY

This study used an experimental method with a pre-test and post-test design involving two groups: an experimental group and a control group. This design was chosen to measure the effectiveness of AI-based media in improving students' critical thinking skills in biology learning, in line with the quantitative research approach used in similar studies (Kim & Zhang, 2025; Lawasi, Rohman, & Shoreamanis, 2024).

Research Design

Experimental Group

Students in the experimental group will use AI-based learning media such as ChatGPT, interactive biology simulations, and NLP-based learning systems

designed to provide adaptive feedback and stimulate reflective thinking (Syafriati, 2024; Gonsalves, 2024; Nugroho & Sari, 2023).

Control Group

The control group will follow the conventional learning method, consisting of lectures and class discussions without AI media intervention. The teaching and learning process will only be sourced from books and written explanations from lecturers.

Research Procedures

Stage 1: Research Preparation

a. Sample Determination: The sample was randomly selected from biology programme students. The total respondents were evenly divided into two groups: experimental and control.
b. Instrument Design: The instrument used was a questionnaire on critical thinking skills, which was developed based on HOTS indicators (Bloom's Taxonomy), using a 1–5 Likert scale:

Table 1. Score

Score	Category
5	Strongly agree
4	Agree
3	Neutral
2	Disagree
1	Strongly disagree

c. Development of AI Media: AI-based learning platforms used include chatbot applications, digital biology simulations, and interactive modules, which have been used effectively in previous studies (Kim & Zhang, 2025; Syafriati, 2024).

Stage 2: Implementation Pre-Test

The pre-test is given to both groups to determine the critical thinking skills of students in the context of biology. The questions cover problem analysis, argument evaluation, and scientific problem solving (Ríos et al., 2025; Ivanova & Petrova, 2024).

Stage 3: Learning Intervention

a. Experimental Group: Followed learning using AI media that enabled direct interaction, data-based simulations, and self-reflection.
b. Control Group: Continues to follow classical learning with lecture methods, question and answer sessions, and discussions without the assistance of AI technology.

Stage 3: Post-Test Implementation

The post-test is given to evaluate the improvement in critical thinking skills. The questions used are equivalent to the pre-test questions in terms of content and level of difficulty.

Stage 4: Data Analysis

The pre-test and post-test data are analysed using SPSS software version 27 with the Independent Sample T-Test statistical test to examine significant differences between the experimental and control groups (Syafriati, 2024; Gonsalves, 2024).

RESEARCH RESULTS

This section presents research findings on the effectiveness of using Artificial Intelligence (AI)-based media in improving students' critical thinking skills in biology learning. Data was collected through pre-test and post-test instruments on two groups, namely the experimental group that received learning using AI media, and the control group that followed conventional learning without AI assistance.

Data processing and analysis were conducted using SPSS version 27 with an Independent Sample T-Test statistical approach. This analysis aims to determine whether there is a significant difference between the critical thinking scores of students from both groups after the learning intervention was carried out. In addition, the results of this study will be reinforced with previous findings to build a theoretical basis and academic validity for the results obtained.

Basic Cognitive Skills in Biological Knowledge of the Excretory System

Table 2. Comparison of Learning Outcomes (Indicators of Basic Cognitive Ability in Biological Knowledge of the Excretory System)

Aspect	**Control Class**	**Experimental Class**	**Description**
Pre-Test			
Number of students (N)	22	19	
Average Value (Mean)	58,18	75,79	Experiment > Control
Standard deviation	13,68	10,71	Variations in the experiment
Sig value (2-tailed)	0,000		There is a significant difference.
Effect of Size (Cohen's id)	-1,42		The big effect
Post-Test			
Number of students(N)	22	19	
Average Value (Mean)	76,36	100,00	All students in the experiment received a score of 100.
Standard deviation	14,65	0,00	There is no variation within the experimental class.
Sig value(2-tailed)	0,000		The difference is very significant.
Effect of Size (Cohen's id)	-2,20		A huge impact

In the pre-test, the experimental class already had significantly higher prior knowledge than the control class. In the post-test, the experimental class experienced a very significant improvement, with all students achieving perfect scores (100). These results indicate that learning interventions (possibly AI-based or other innovative approaches) are very effective in improving students' basic cognitive abilities. Based on the results of the pre-test and post-test data analysis, there was a significant difference between the control class and the experimental class in terms of basic cognitive ability (knowledge of the excretory system). This is indicated by the significance value (Sig. 2-tailed) in the t-test, which is 0.000 for both the pre-test and post-test, with the post-test average score for the experimental class being 100.00 and for the control class being 76.36. This significant improvement indicates that the learning intervention provided to the experimental class had a very strong positive impact on improving students' knowledge. The effect size (Cohen's d = 2.20) is classified as very large, indicating that this improvement did not occur by chance but was the result of an effective learning strategy.

Critical Thinking Skills

Table 3. Comparison of Learning Outcomes (Critical Thinking Ability Indicators)

Aspect	**Control Class**	**Experimental Class**	**Description**
Pre-Test			
Number of students (N)	22	19	
Average Score (Mean)	64,55	77,89	Experiment > Control
Standard Deviation	16,25	6,31	Smaller variation in experiments
Sig value (2-tailed)	0,002		There are significant differences
Size Effect (Cohen's id)	-1,05		Large effect
Post-Test			
Number of students(N)	22	19	
Average score(Mean)	73,64	100,00	Total number of students in the experiment = 100
Significance value	16,77	0,00	No variation in the experiment
Nilai Sig. (2-tailed)	0,000		Very significant difference
Effect size(Cohen's id)	-2,14		Very large effect

A Sig. value < 0.05 in both the pre-test and post-test indicates that there is a significant difference between the control class and the experimental class. The intervention in the experimental class (e.g., innovative learning approaches or

AI-based learning) had a significant effect on improving students' critical thinking skills.

The results of the pre-test and post-test data analysis on critical thinking ability indicators show that there is a significant difference between the control class and the experimental class. The significance value (Sig. 2-tailed) of the t-test on the pre-test is 0.002, and on the post-test is 0.000, both of which are below the significance level of 0.05. This indicates that the difference between the two classes is not due to chance, but rather the result of the treatment or intervention given to the experimental class.

The experimental class experienced a very high increase in learning outcomes, with an average post-test score of 100, while the control class only achieved 73.64. The effect size (Cohen's d) of 2.14 falls into the category of a very large effect, indicating that the treatment given to the experimental class had a very strong influence on the improvement of students' critical thinking skills.

Learning Using AI and Without Using AI

Table 4. Comparison of Learning Using AI vs. Without AI

Aspect	**Control Class (Without AI)**	**Experimental Class (With AI)**
Number of students(N)	22	19
Pre-Test (Mean)	66.36	73.68
Post-Test (Mean)	72.73	97.89
Score improvement (Δ)	+6.37	+24.21
Sig. (2-tailed)	0.151 i(insignificant)	0.000 (very significant)
Effect size(Cohen's d)	-0.458 i(small)	-1.809 i(very large)

The experimental class that utilised AI in learning demonstrated an improvement in scores that was more than three times higher than the control class. The effect size is very large (Cohen's d = 1.809), indicating a very significant practical and statistical impact on learning outcomes in terms of technology use. Learning without AI still showed improvement, but it was not statistically significant.

This study compares the learning outcomes between two groups: the experimental class that uses artificial intelligence (AI) technology in the learning process, and the control class that uses manual review methods without AI. Based on the pre-test and post-test data, a clear picture was obtained regarding the effectiveness of using AI in improving the learning outcomes of students. Quantitative results were obtained through pre-test and post-test. In the pre-test stage, the average score for the control class was 66.36 and for the experimental class was 73.68. Although there was a difference, the test results showed a Sig. (2-tailed) = 0.151, which means that the difference is not statistically significant. This means that both classes can be considered to have comparable initial abilities. However, in the post-test, the results show that the average score of the

control class increased to 72.73, while the experimental class increased dramatically to 97.89. The test produced a Sig. (2-tailed) value of 0.000, indicating a statistically significant difference. The effect size (Cohen's d) of -1.809 also shows that the impact of AI use on learning outcomes is very large.

Results of Student Perception Survey

Based on the results of the questionnaire analysed using SPSS, data was obtained on students' perceptions of the use of technology in learning. There were two classes compared: Class A (Control): Learning was conducted manually, without the aid of AI. Class B (Experimental): Learning used artificial intelligence (AI)-based technology.

Table 5. Summary of Average Scores for Each Statement:

Statement	Control class (without AI)	Experimental class (with AI)
Able to review videos about the excretory system	4.18	4.47
Able to understand the content of educational videos	4.50	4.37
Able to understand biological processes.	4.36	4.11
Able to review educational videos in other courses	3.86	4.78
Able to review videos, create learning materials, and make learning more enjoyable.	4.41	4.32

The graph above shows that, in general, the experimental class gave higher or equivalent perception scores on most indicators compared to the control class.

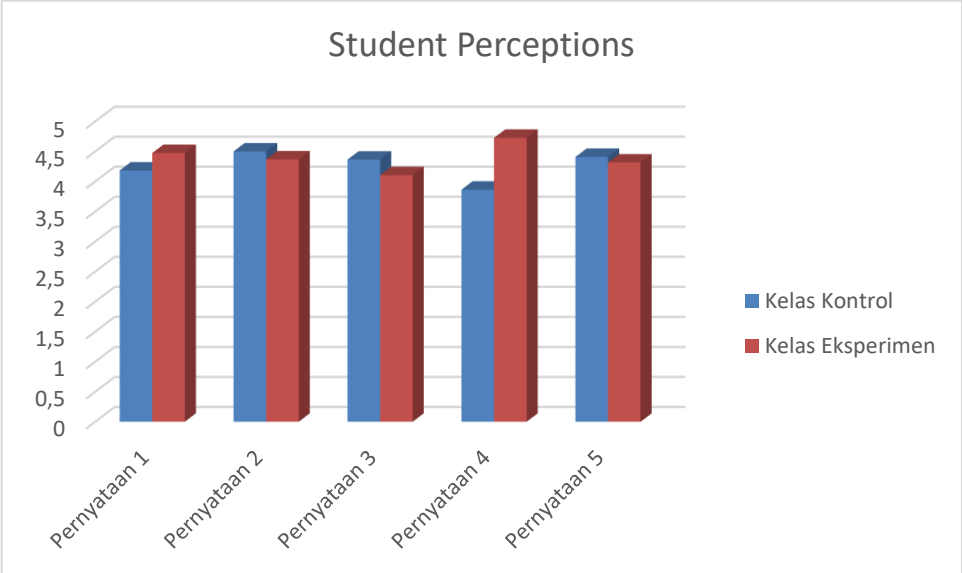

Figure 2. Bar chart showing students' perceptions after completing the learning process

More Positive Responses in AI Classes: Students who learn with the help of AI tend to have more positive perceptions, especially in terms of technological support, ease of understanding the material, and interactive learning experiences.

DISCUSSION

The results of this study are in line with the findings of Papaneophytou & Nicolaou (2025), who stated that the integration of artificial intelligence (AI) technology in biology learning can enrich the learning process through a problem-based and reflective approach. AI helps simplify complex concepts such as the excretory system through simulation, visual explanations, and in-depth automatic evaluation. The results of this study are in line with the findings of Papaneophytou & Nicolaou (2025), who stated that the integration of artificial intelligence (AI) technology in biology education can enrich the learning process through a problem-based and reflective approach. AI helps simplify complex concepts such as the excretory system through simulation, visual explanations, and in-depth automatic evaluation.

Furthermore, Kim & Zhang (2025) also found in their case study that learning that combines AI literacy in a biological context can improve students' conceptual understanding, although they emphasise the importance of teacher involvement in bridging students' understanding of abstract concepts.

Additional support comes from Ivanova and Petrova (2024), who state that the use of AI based on information understanding can strengthen students' ability to analyse and understand material better. However, they also emphasise the need for supervision to ensure that students do not become overly dependent and continue to maintain their independent thinking skills.

In the context of Bloom's taxonomy, as explained by Gonsalves (2024), the aspects of knowledge and understanding are included in the basic cognitive level, which can be strengthened with AI if used reflectively. AI can facilitate students in accessing information, organising concepts, and answering interactive quizzes that strengthen their memory and understanding of biology. These findings indicate that the use of technology, particularly artificial intelligence, in biology education can be highly effective in strengthening students' mastery of basic knowledge. However, this success is also influenced by the pedagogical strategies used, such as active learning, scaffolding by teachers, and the use of interactive learning media. It is important for educators not to rely solely on AI as a tool for automation, but also as a medium to stimulate students' cognitive engagement actively, as recommended by Lawasi et al. (2024) in their research on the use of AI in developing thinking skills.

According to Papaneophytou & Nicolaou (2025), in the AI era, it is important for science learning to not only rely on technology as a tool for information, but also as a stimulus for reflective, ethical, and contextual thinking. In this context, the use of AI such as chatbots, automatic feedback systems, and problem-based learning is very effective in challenging students to evaluate information, identify biases, and make decisions based on evidence. This is reinforced by Gonsalves (2024), who states that learning that uses AI must be designed to reinforce the upper levels of Bloom's taxonomy—namely analysis,

evaluation, and synthesis—which are the core of critical thinking. AI can help through simulation, automatic assessment, and interactive scenarios, but the success of learning still depends on the ability of students to analyse, reason, and evaluate the answers generated by the AI system. Ivanova & Petrova (2024) also state that although AI is very helpful in improving critical thinking skills, there are concerns about over-reliance on instant answers from automated systems, which can actually weaken independent thinking if not monitored. Therefore, it is important for teachers to guide students in criticising and evaluating information, rather than simply accepting answers from AI. In a study by Lawasi et al. (2024), it was found that students who used AI effectively by asking follow-up questions and evaluating answers showed a significant improvement in critical thinking. They not only learn from AI, but also practise reflective and analytical thinking, which are characteristic of critical thinking.

These findings are consistent with research by Kim and Zhang (2025), which shows that integrating AI literacy learning into biology classes can improve students' conceptual understanding and strengthen interdisciplinary connections through active and contextual learning. Similarly, Papaneophytou & Nicolaou (2025) emphasise the importance of higher education in instilling critical thinking skills in the AI era. AI is considered not only as a tool, but also as a key driver in creating a learning environment that supports analysis, reflection, and evidence-based reasoning. In this context, learning with AI also supports the higher-order thinking skills (HOTS) approach as outlined in Bloom's expanded taxonomy. According to Gonsalves (2024), AI can accelerate the achievement of analytical and evaluative skills, but it still requires the role of teachers in guiding the reflective and ethical process.

AI Enhances Engagement and Understanding in Line with Findings from Lawasi et al. (2024), the use of AI such as chatbots or adaptive systems in learning has been proven to provide a more personalised and in-depth learning experience, which can improve students' critical thinking skills. Reflection on the Effectiveness of AI Use Research by Papaneophytou & Nicolaou (2025) also emphasises that AI can be a very effective tool if used with appropriate pedagogical guidance, as it can encourage reflective and evaluative thinking, which forms the basis of critical thinking in science. The graphs and data show that AI-based learning has a positive impact on students' perceptions, particularly in terms of ease of understanding the material, increased interest in learning, and a more adaptive learning experience. This reinforces the importance of integrating AI-based technology into higher education to improve the quality of learning.

CONCLUSIONS AND RECOMMENDATIONS

This study proves that Artificial Intelligence (AI)-based learning has a positive and significant impact on improving:

1. Basic cognitive abilities in knowledge of the excretory system, with a significance value (Sig. 2-tailed) of 100.00 for the post-test in the experimental class and 76.36 for the control class. This significant improvement indicates

that the learning intervention provided to the experimental class had a very strong positive impact on improving students' knowledge.

2. Critical thinking skills: the results of the pre-test and post-test data analysis on critical thinking skills indicators show that there is a significant difference between the control class and the experimental class. The significance value (Sig. 2-tailed) of the t-test on the pre-test is 0.002, and on the post-test is 0.000, both of which are below the significance level of 0.05.
3. Learning with AI and without AI, the experimental class that used AI in learning showed an increase in scores more than three times that of the control class. The effect size was very large (Cohen's d = -1.809), indicating a very significant practical and statistical impact on learning outcomes in terms of technology use. Learning without AI still showed improvement, but it was not statistically significant.
4. Student Perception Questionnaire Results, in general, the experimental class gave higher or equivalent perception scores on most indicators compared to the control class.

ADVANCED RESEARCH

Although this study shows significant results, there are several limitations that need to be considered in its interpretation and application. To expand and deepen the scope and findings of research on AI-based learning, the following recommendations are suggested for future researchers: conducting longitudinal studies, using larger and more diverse samples, incorporating new variables, exploring alternative learning methods or technologies, and integrating mixed-methods approaches.

ACKNOWLEDGMENT

The author would like to express sincere gratitude to all parties, especially the Biology Education Study Programme and the Faculty of Teacher Training and Education, for their financial support and contributions to the implementation, preparation, and completion of this research. The funding for this research was provided by the Directorate General for Research and Development Strengthening, Ministry of Research, Technology, and Higher Education, under DIPA Number DIPA-139.03.2.693394/2025.

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