International Journal of Emerging Research and Review
Homepage : https://ijoerar.net/index.php/ijoerar
p-ISSN : 3024-8825; e-ISSN : 3021-8950

IJOERAR, Vol. 4, No. 2, June 2026

Effectiveness of the ICARE-Modification Model in Training Students' Critical Thinking Skills

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DOI: https://doi.org/10.56707/ijoerar.v4i2.168

Sections Info

Article history:
Submitted: March 03, 2026
Final Revised: March 13, 2026
Accepted: March 14, 2026
Published: April 08, 2026

Keywords:
ICARE-modification
Critical thinking
AI-assisted learning
Students
Lecture

ABSTRACT

Objective: *Developing students' critical thinking skills remains a central challenge in higher education, particularly in teacher education programs that demand higher-order cognitive competencies. This study investigates the effectiveness of the ICARE-Modification model—an extended instructional framework integrating Introduction, Connection, Application-modification, Reflection, and Extension stages with AI problem-solving activities—in enhancing undergraduate students' critical thinking skills.* ***Method:*** *A quasi-experimental design with a non-equivalent control group was employed involving 60 undergraduate students enrolled in a teacher education program. The experimental group received instruction using the ICARE-Modification model, while the control group experienced conventional lecture-based learning. Data were collected through a validated open-ended critical thinking test assessed using an analytical rubric covering questioning, analysis, evaluation, logical reasoning, and solution formulation. Data were analyzed using independent samples t-tests and Cohen's d effect size.* ***Results:*** *The findings suggest that the ICARE-Modification model creates a more interactive and cognitively engaging learning environment that supports the development of students' critical thinking skills. Through structured stages of learning that involve exploration, discussion, and reflection, students are encouraged to actively construct knowledge and evaluate their own reasoning processes, which ultimately leads to better learning outcomes in critical thinking.* ***Novelty:*** *This study introduces the ICARE-Modification model, an extended instructional framework that integrates the traditional ICARE stages with AI-assisted problem-solving activities to foster students' critical thinking skills in teacher education. Unlike previous studies that apply ICARE as a conventional instructional model, this research incorporates structured cognitive scaffolding and AI-supported reflective learning to enhance higher-order thinking processes.*

INTRODUCTION

The rapid advancement of science and technology in the era of the Industrial Revolution 4.0 and Society 5.0 has fundamentally transformed the demands placed upon higher education institutions. Universities are no longer expected merely to transmit disciplinary knowledge; they are required to cultivate graduates equipped with Higher Order Thinking Skills (HOTS), particularly critical thinking skills. In an increasingly complex and data-driven world, critical thinking enables students to analyze information rigorously, evaluate competing arguments, make evidence-based decisions, and systematically address multifaceted problems. Consequently, critical thinking has become a central indicator of instructional quality and graduate competitiveness in higher education (Ibtidaiyah, 2024).

Conceptually, critical thinking encompasses the ability to identify problems, formulate relevant questions, analyze empirical evidence, evaluate the credibility of arguments, draw logical conclusions, and reflect upon one's reasoning processes (Ariadila et al., 2023). Within Bloom's revised taxonomy, these competencies align with higher-order cognitive domains—analyzing, evaluating, and creating. However, despite its recognized importance, numerous studies indicate that university students often demonstrate limited proficiency in argument evaluation and analytical reasoning (Gazali & Dasna, 2023). One major contributing factor is the persistence of teacher-centered instructional practices, where knowledge transmission dominates classroom interaction. Such approaches tend to minimize opportunities for inquiry, reflection, and cognitive engagement, thereby restricting the development of higher-order thinking (Mardliyah et al., 2023; Mulyani, 2022; Putri et al., 2025).

Addressing this challenge requires instructional models that intentionally integrate cognitive, metacognitive, and reflective processes. The ICARE framework—comprising Introduction, Connection, Application, Reflection, and Extension—has been recognized as a structured model supporting meaningful learning through sequential cognitive engagement. By activating prior knowledge, contextualizing concepts, and encouraging reflective consolidation, ICARE aligns with constructivist principles that emphasize active knowledge construction. Nevertheless, previous implementations of ICARE in certain contexts have not fully optimized deep problem exploration or evidence-based argumentation. In particular, the Application stage often remains procedural rather than analytical, limiting opportunities for sustained evaluative reasoning (Rahardhian, 2022; Suparni, 2016).

To overcome these limitations, this study proposes the ICARE-Modification model, which extends the original framework by integrating problem-solving elements and Artificial Intelligence (AI) as a form of cognitive scaffolding. AI-supported learning environments, when embedded within structured pedagogical design, have been shown to enhance analytical engagement and reflective inquiry. Rather than functioning as a passive information source, AI can stimulate critical examination when students are required to compare, critique, and validate generated outputs. Furthermore, metacognitive regulation—closely associated with reflective monitoring—plays a crucial role in critical thinking development. By strengthening the Application and Reflection stages with HOTS-based tasks and AI-assisted inquiry, the ICARE-Modification model seeks to promote deeper analytical reasoning and argument evaluation.

In the modified Application stage, Higher Order Thinking Skills (HOTS)-based open-ended questions and contextual case studies in Plant Ecology are incorporated to stimulate analytical and inferential reasoning. Students are required to identify problems, analyze observational data, formulate assumptions, compare alternative solutions, and justify conclusions with evidence. This transformation shifts the Application phase from procedural practice to a platform for authentic problem-solving and argumentative dialogue (Anggraini et al., 2024; Wardani & Fiorintina, 2023). The Reflection stage further reinforces metacognitive awareness by prompting students to evaluate their reasoning processes and decision-making strategies (Endrawan & Aliriad, 2023; Latifah, 2023; Mimhamimdala & Nirwana, 2023).

Previous research was implemented in adult training or applied the ICARE model using an adult-learning approach, so the results did not fully achieve the intended objectives. In addition, the implementation of ICARE was not carried out with clearly structured syntax and activity divisions, making the learning process more teacher-centered.

In contrast, this study implements an ICARE-Modification model and aims to improve students' critical thinking skills in the Plant Ecology course. The modification is made in the Application syntax, where students engage in group activities through e-learning to solve environmental cases based on questions designed by the lecturer. Students complete their tasks with the assistance of AI to obtain updated results and the latest information, which are then aligned with findings from research that has been published in reputable journal articles.

Critical thinking is considered one of the essential competencies in higher education, as it enables students to analyze information, evaluate evidence, formulate assumptions, and make reasoned decisions when solving problems. According to Robert H. Ennis, critical thinking involves reflective and rational thinking that focuses on deciding what to believe or do. Similarly, Peter A. Facione emphasizes that critical thinking includes skills such as analysis, interpretation, inference, evaluation, and explanation. Therefore, learning strategies should be designed to actively engage students in processes that stimulate these cognitive skills. One learning model that supports this objective is the ICARE model, which consists of five stages: Introduction, Connection, Application, Reflection, and Extension. These stages provide structured learning experiences that encourage students to analyze problems, connect new knowledge with prior understanding, apply concepts to real situations, and evaluate their own learning processes. The Application and Reflection stages, in particular, provide opportunities for students to engage in problem-solving and evaluative thinking, which are core elements of critical thinking. Consequently, the ICARE learning model theoretically aligns with the development of critical thinking skills because its instructional structure promotes active inquiry, analysis, and reflective learning processes(Saputra, 2026).

The ICARE-Modification learning model consists of five sequential stages that are designed to facilitate meaningful and student-centered learning. The **Introduction** stage aims to introduce the learning objectives and provide an overview of the topic while stimulating students' curiosity through guiding questions or contextual problems. The Connection stage encourages students to relate new knowledge to their prior knowledge and experiences, enabling them to construct a deeper conceptual understanding. The Application-Modification stage serves as the core of the learning process, where students actively apply the concepts they have learned to solve problems, analyze cases, or complete collaborative tasks, thereby promoting analytical and critical thinking skills. The Reflection stage provides opportunities for students to evaluate their learning experiences, express their understanding, and identify difficulties encountered during the learning process, which supports the development of metacognitive awareness. Finally, the Extension stage aims to broaden and deepen students' knowledge by encouraging further exploration through independent learning activities, additional readings, or investigations related to the topic. Through these structured stages, the ICARE-Modification model supports active engagement, knowledge construction, and higher-order thinking in the learning process (Roikha et al., 2023).

The ICARE-Modification learning model can theoretically support the development of critical thinking skills because its instructional structure encourages students to engage in higher-order cognitive processes. Through systematic learning stages, students are not merely recipients of information but are actively involved in processing, analyzing, and evaluating the knowledge they acquire. In this process, students are trained to develop analytical reasoning, which refers to the ability to identify relationships between concepts, analyze information, and interpret data or phenomena being studied. In addition, learning activities that involve discussion, reflection, and the assessment of

IJOERAR, Vol. 4, No. 2, June 2026

various alternative solutions can enhance evaluation skills, namely the ability to assess the accuracy of information, consider evidence, and make logical judgments. Furthermore, through activities such as case studies, environmental problem analysis, and collaborative group work during the application stage, students are encouraged to develop problem-solving skills by integrating their knowledge to identify appropriate solutions to the problems presented. Therefore, the conceptual relationship between the stages of the ICARE-Modification model and the development of analytical reasoning, evaluation skills, and problem-solving abilities provides a stronger theoretical foundation for explaining why the implementation of this model is expected to improve students' critical thinking skills (Nikmah et al., 2025).

Although the ICARE-Modification model is theoretically grounded in constructivism, cognitive scaffolding, and metacognitive theory, empirical validation of its effectiveness in higher education contexts remains limited. Existing research has examined ICARE or AI-supported learning independently; however, few studies have systematically integrated both within a coherent instructional framework aimed specifically at strengthening critical thinking skills in teacher education. This gap underscores the need for rigorous experimental investigation (Nadia, 2025; Nisa et al., 2023).

Therefore, this study aims to analyze the effectiveness of the ICARE-Modification model in training undergraduate students' critical thinking skills by measuring improvements in critical thinking indicator achievement before and after the intervention. By providing empirical evidence of its impact, this research contributes theoretically to the advancement of integrative instructional design in the AI era and practically to the development of adaptive, evidence-based teaching strategies in higher education.

RESEARCH METHOD

This study employed a quasi-experimental research design with a quantitative descriptive approach. It aimed to examine the effect of the ICARE-Modification learning model on improving students' critical thinking skills. The aspects of critical thinking competence investigated included the ability to analyze observation results, questioning skills, and the ability to make AI-assisted assumptions (Norsaniyah et al., 2025; Rayanto & Supriyo, 2022; Sappaile et al., 2025). The quasi-experimental method is appropriate for this study because it aims to examine the effect of implementing the ICARE-Modification model on improving students' critical thinking skills in a real learning setting without full randomization of the research subjects. This research was conducted at the Faculty of Teacher Training and Education, Biology Education Study Program, Universitas Mulawarman. The sample consisted of 30 students from Class A, comprising 12 male students and 18 female students. The sample was selected using a purposive sampling technique, in which participants were chosen based on specific criteria relevant to the research objectives. The selected participants were students enrolled in the Plant Ecology course in the Biology Education Study Program at Universitas Mulawarman. Class A, consisting of 30 students, was chosen as the research sample because the class was actively participating in the course where the ICARE-Modification learning model was implemented. The complete research procedure is presented in Figure 1. This study applied a quasi-experimental method using a one-group pre-test and post-test design, involving one experimental class without a control group, as shown in Table 1.

Tabel 1. Research Design

Group	Pretest	Treatment	Postest
Experiment	Q1	X	Q2

Description
O1 : Pretest given before treatment
X : Treatment in applying the ICARE-Modification Model for treatment class
O2 : Posttest given after treatment

Data were collected using a critical thinking skills test instrument enriched with Higher Order Thinking Skills (HOTS) question types. The critical thinking test addressed the topic of plant ecology, specifically the history of plant ecology. The test instrument consisted of 16 essay items designed based on three indicators of critical thinking skills: (1) questioning skills, (2) the ability to analyze observation results, and (3) the ability to make assumptions (Shanzey et al., 2025).

The validation results of the critical thinking test instrument, conducted by three experts, were analyzed using Aiken's Validity Coefficient (Aiken, 1985) with the following formula:

$$V=\sum s / \{ n(c-1) \}$$

Description
V : Validity score
S : The score given by the validator minus the lowest score in the category
n : Number of validator
C : Highest score

Learning Procedure

The implementation of the ICARE-Modification model in this study was carried out through several stages. First, during the introduction stage, the lecturer presented the learning objectives and introduced contextual environmental problems relevant to the topic being studied. Second, in the connection stage, students were encouraged to relate the presented problems to their prior knowledge through guided discussions. Third, during the application stage, students worked collaboratively in small groups to analyze environmental case studies through an e-learning platform and utilized AI-assisted tools to obtain relevant and up-to-date scientific information. Fourth, in the reflection stage, students evaluated the reasoning processes used during the discussion, compared various arguments that emerged, and identified the strengths and weaknesses of the proposed solutions. Finally, in the extension stage, students were encouraged to explore additional learning resources to broaden and deepen their understanding of the ecological issues discussed during the learning process.

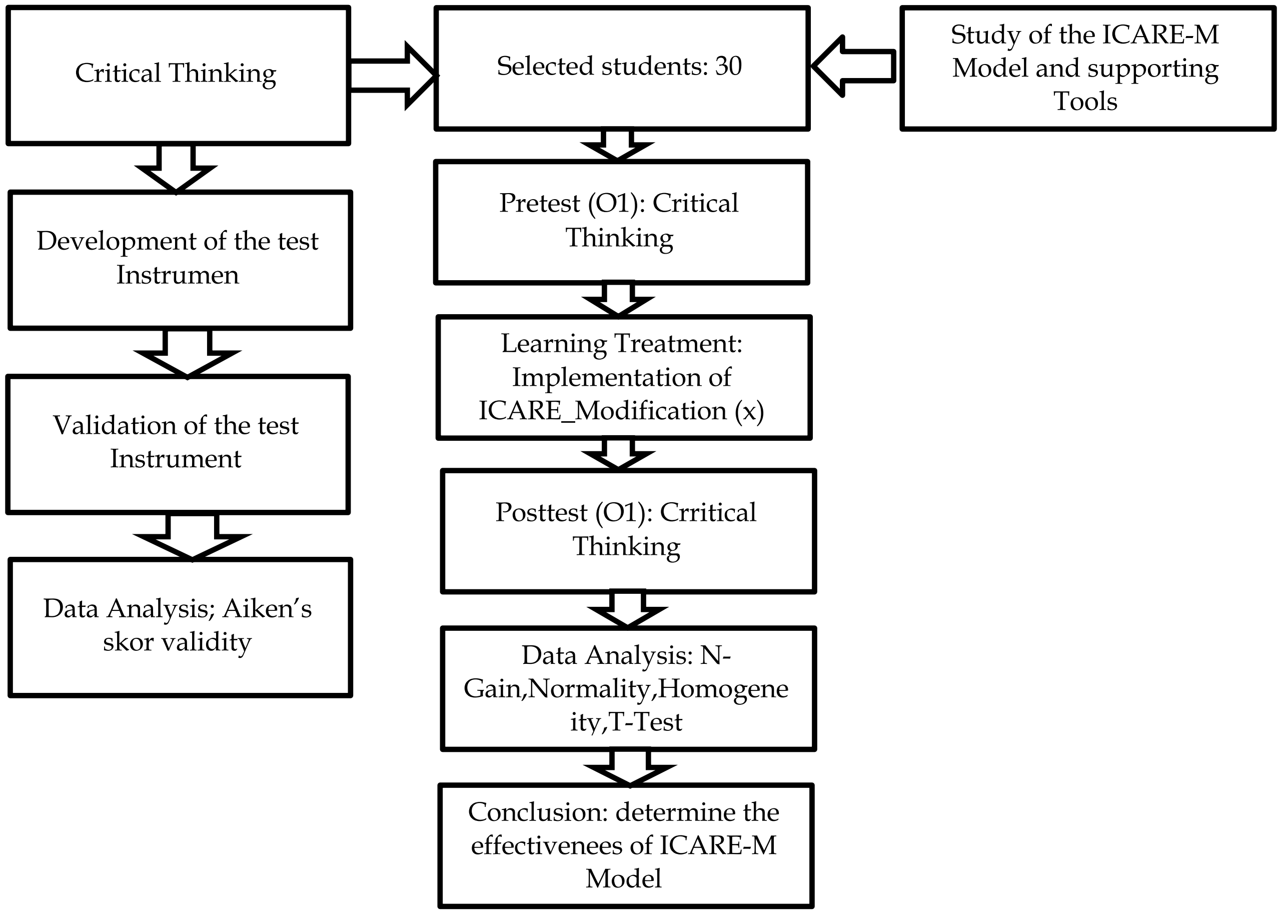

Figure 1. Research Prosedure

Table 2. Modification of the ICARE-Modification Model

No	ICARE Stage	Original ICARE Learning Activities	ICARE-Modification Learning Activities in This Study
1	Introduction	The lecturer introduces the learning objectives and provides an overview of the material to be studied.	The lecturer introduces environmental issues relevant to the learning material and provides guiding questions to stimulate students' initial thinking.
2	Connection	Students connect new concepts with their prior knowledge through discussion or question-and-answer activities.	Students discuss environmental phenomena and relate them to their existing knowledge and previous learning experiences.
3	Application	Students apply concepts through exercises, assignments, or simple discussions. Students apply concepts through exercises, assignments, or simple discussions.	Students work in groups to analyze environmental case studies through e-learning, formulate questions, and construct arguments using AI-assisted tools to obtain updated scientific information.

No	ICARE Stage	Original ICARE Learning Activities	ICARE-Modification Learning Activities in This Study
4	Reflection	Students summarize the material learned and reflect on the learning process.	Students evaluate the results of group discussions, review the arguments they developed, and reflect on the reasoning processes used to solve the case.
5	Extension	Students complete follow-up assignments or additional learning activities.	Students explore additional references such as scientific articles or research reports to deepen their understanding of the environmental issues studied.

Tabel 3. Learning Activities

Learning Stage	Learning Objective	Lecture Activities	Student Activities	Duration
Introduction	To introduce the learning topic and stimulate students' curiosity about the environmental issues to be studied.	Explains the learning objectives, presents relevant environmental phenomena or cases, and provides guiding questions.	Listen to the lecturer's explanation, observe the presented phenomena, and respond to guiding questions to identify the initial problem.	10–15 minutes
Connection	To connect students' prior knowledge with the new concepts to be learned.	Leads the initial discussion and asks questions that relate previous material to the topic being studied.	Express opinions, relate previous knowledge or experiences to the given problem, and discuss ideas with classmates.	15–20 minutes
Application *(Modified Stage)*	To apply concepts to analyze real-world problems and develop students' critical thinking skills.	Provides environmental case studies through an e-learning platform, facilitates group discussions, and guides students in the case analysis process.	Work in groups to analyze environmental cases, gather information from various sources, use AI assistance to obtain updated scientific information, and construct arguments and solutions based on the data obtained.	40–45 minutes

Learning Stage	Learning Objective	Lecture Activities	Student Activities	Duration
Reflection	To evaluate students' understanding and reflect on the thinking processes used during learning.	Facilitates a reflection session and asks students to explain the results of their discussions and the reasoning behind the proposed solutions.	Present group analysis results, evaluate the arguments developed, and reflect on the reasoning processes used to solve the problem.	15–20 minutes
Extension	To broaden and deepen students' understanding of the concepts learned.	Provides follow-up tasks or additional references related to the environmental issues studied.	Explore additional references such as scientific articles, research reports, or other academic sources to deepen their understanding of the learning topic.	10–15 minutes

Then, the data validatity score obtained is categorized as per Table 4.

Table 4. Validation Criteria for the ethnoscience literacy test instrument

Score Interval	Criteria	Meaning
0.75≤ V<1.00	Very valid	Can be use without revision
0.50≤ V<0.75	Valid	Can be used sith minor revision
0.25≤ V<0.50	Quite Valid	Can be used with mayor revision
0.00≤ V<0.25	Less Valid	Not yet Useble

The validity assessment results indicated that 7 out of the 16 items obtained an average Aiken's validity coefficient of 1.00, which was categorized as "very valid." Meanwhile, 8 items with a coefficient of 0.92 and 2 items with a coefficient of 0.86 were also categorized as "very valid." The reliability test using Cronbach's Alpha demonstrated a good level of reliability. Subsequently, the critical thinking instrument was used to collect pre-test and post-test data to measure the effectiveness of the ICARE-Modification model in improving students' critical thinking skills. The data were further analyzed using a normality test, homogeneity test, and paired-sample t-test. The normalized gain (n-gain) formula was employed to determine the difference between pre-test and post-test scores. The average n-gain was calculated by the following formula:

$$\text{N-Gain} = \frac{post\ test\ score - pre\ test\ score}{Maximum\ score - pre\ test\ score}$$

Then, the n-gain obtained is categorized based on the following table 5.

Table 5. The N-Gain Criteria

N-Gain Score	Criteria
0.70, n-gain	High
0.30 ≤ n-gain ≤ 0.70	Average
n-gain < 0.30	Low

Normality Test

The statistical formula for the Shapiro–Wilk test is as follows:

$$W = \frac{\left(\sum_{i=1}^{n} a_i\, x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Description:

W = Shapiro–Wilk test statistic
n = sample size
x_(i) = the i-th ordered data value arranged from the smallest to the largest
x̄ = sample mean
a_i = Shapiro–Wilk constants (coefficients) obtained from the expected values and covariance of the order statistics of a normal distribution

The formula for the Paired Sample t-test is as follows:

$$t = \frac{\bar{d}}{S_d/\sqrt{n}}$$

Description:

t = t-test statistic value
d̄ = mean difference between pre-test and post-test scores
S_d = standard deviation of the difference scores
n = sample size

RESULTS AND DISCUSSION

Results

The results of the observation of students' critical thinking skills test indicate a significant effect. The results of the limited trial were measured using quantitative descriptive analysis based on the pretest, posttest, and N-gain scores. Data on students' critical thinking skills were obtained through a test instrument consisting of HOTS (Higher Order Thinking Skills) questions, which included 16 essay-type questions. A summary of the descriptive scores of the pretest, posttest, and N-gain of students' critical thinking skills in the limited trial is presented in Table 6.

Table 6. Description of the pretest,postest and N-Gain Score of student's Critical Thinking

Initial Student	Pretest	Postest	N-gain	Criteria
SC 1	20	93	0.91	High
SC 2	24	87	0.83	High
SC 3	43	92	0.86	High
SC 4	25	86	0.82	High
SC 5	34	88	0.82	High
SC 6	21	84	0.80	High
SC 7	26	93	0.91	High
SC 8	43	85	0.74	High
SC 9	21	87	0.84	High
SC 10	35	97	0.96	High

Initial Student	Pretest	Postest	N-gain	Criteria
SC 11	32	84	0.78	High
SC 12	24	87	0.83	High
SC 13	43	86	0.76	High
SC 14	35	88	0.86	High
SC 15	26	86	0.82	High
SC 16	31	87	0.82	High
SC 17	57	89	0.75	High
SC 18	21	90	0.88	High
SC 19	65	92	0.79	High
SC 20	68	93	0.79	High
SC 21	68	96	0.88	High
SC 22	34	87	0.81	High
SC 23	53	89	0.77	High
SC 24	38	86	0.78	High
SC 25	32	85	0.78	High
SC 26	34	85	0.78	High
SC 27	21	87	0.84	High
SC 28	54	88	0.74	High
SC 29	18	90	0.88	High
SC 30	21	85	0.88	High
Average N-Gain			0.82	
Criteria				High

Based on the data presented in Table 6, it can be observed that there is a significant difference in students' critical thinking skills after the implementation of the ICARE-Modification model. The test results before the treatment using the ICARE-Modification model (pretest) showed low scores ranging from 18.00 to 68.00, with an average score of 35.5. After the implementation of the ICARE-Modification model through three learning sessions followed by a posttest, there was a significant improvement in students' critical thinking skills, with scores ranging from 84.00 to 97.00 and an average score of 88.40.

Discussion

One important indicator for measuring learning effectiveness is the calculation of the N-gain score. The N-gain analysis describes the level of improvement in students' critical thinking skills before and after the learning process using the ICARE-Modification model. The high average N-gain score of 0.71, which falls into the high category, indicates that the ICARE-Modification model was successful in significantly training students' critical thinking skills. Another important finding is that all students experienced improvements in their critical thinking skills, with every student obtaining a minimum posttest score of 84.00 or higher.

This improvement is particularly evident among students who obtained the lowest scores during the pretest. For example, ten students obtained the lowest pretest scores of 18.00 and around 20, but after participating in learning using the ICARE-Modification model, they achieved relatively high posttest scores.

The significant improvement in students' critical thinking skills after the implementation of the ICARE-Modification model can be explained through the learning processes embedded in its instructional stages, particularly the application and reflection stages, which actively engage students in higher-order cognitive activities. In the application stage, students are required to analyze environmental cases, discuss possible solutions, and construct arguments based on available information and scientific evidence. These activities encourage cognitive engagement, as students must interpret data, evaluate different perspectives, and justify their reasoning when solving problems. Such learning processes align with the principles of inquiry-based learning, where students actively investigate problems and construct knowledge through exploration and reasoning rather than passively receiving information. Meanwhile, the reflection stage provides opportunities for students to review and evaluate their understanding of the concepts learned, assess the strengths and weaknesses of their arguments, and reconsider the reasoning processes they used during problem-solving. This stage promotes argument evaluation and metacognitive processes, as students become aware of how they think, analyze their own learning strategies, and regulate their understanding. From a theoretical perspective, these learning activities are closely related to constructivist learning theory, which emphasizes that knowledge is actively constructed through interaction, experience, and reflection. According to constructivist principles, meaningful learning occurs when students actively connect new knowledge with prior understanding and reflect on their learning experiences. Therefore, the structured activities within the ICARE-Modification model, particularly through the application and reflection stages, create a learning environment that supports active inquiry, critical analysis, and metacognitive awareness. This theoretical foundation explains why the implementation of the ICARE-Modification model was able to significantly improve students' critical thinking skills, as reflected in the high N-gain score and the consistent improvement in posttest results among all students (Rahmadhani et al., 2022).

Table 7 shows that the implementation of the ICARE-Modification model had a positive impact on improving students' critical thinking skills at the university. This is indicated by the average N-gain score of 0.82, which is categorized as high for critical thinking skills.

Tabel 7. N-Gain Scrore for each Indicators of critical Thinking Asisted AI

Indicator of critical Thinking	Question Number	Pretest	Postest	N-Gain	Criteria
Questionng Skills	2,4,8,12,14	21	85	0.88	High
Ability to Analyze Observation Result	1, 2, 4, 7, 9, 10,13,16	20	93	0.91	High
Ability to Make Assumptions	3,6,10,11,12,15,	24	87	0.83	High
Average N-Gain				0.84	
Criteria					High

The statistical results show that the implementation of the ICARE-Modification model significantly improved students' critical thinking skills across all indicators. This is reflected in the high N-gain scores for questioning skills (0.88), ability to analyze observation results (0.91), and ability to make assumptions (0.83), with an overall average N-gain of 0.84, which falls into the high category. These findings suggest that the learning activities embedded in the ICARE-Modification model effectively stimulated students' higher-order thinking processes during the learning sessions.

One of the key factors contributing to this improvement is the application stage of the ICARE-Modification model. In this stage, students actively engage in solving environmental cases and analyzing real-life problems through collaborative discussions and AI-assisted exploration of scientific information. Such activities require students to interpret data, examine evidence, and construct logical explanations, which directly support the development of cognitive engagementand analytical reasoning. Through these processes, students are encouraged to formulate questions, analyze observation results, and generate assumptions based on available information. These activities are closely aligned with the principles of inquiry-based learning, which emphasize active investigation, questioning, and problem-solving as central components of meaningful learning (Siahaan et al., 2020).

Another important stage that contributes to the development of critical thinking is the reflection stage. In this stage, students evaluate the results of their discussions and reconsider the arguments or solutions they proposed during the learning process. This reflection encourages students to assess the validity of their reasoning, compare different perspectives, and refine their understanding of the concepts learned. As a result, the reflection stage promotes argument evaluation and strengthens metacognitive processes, where students become aware of how they think, monitor their reasoning, and regulate their learning strategies (Usri & Ikbal Salam, 2024).

From a theoretical perspective, these learning processes are consistent with the principles of constructivist learning theory, which states that knowledge is actively constructed through interaction, experience, and reflection. Constructivism emphasizes that students learn more effectively when they are actively involved in exploring problems, connecting new knowledge with prior experiences, and reflecting on their learning processes. Therefore, the ICARE-Modification model provides a structured learning environment that encourages students to actively construct knowledge through inquiry, discussion, and reflection. This theoretical foundation explains why the implementation of the ICARE-Modification model was able to significantly improve students' critical thinking skills, as indicated by the consistently high N-gain scores across all critical thinking indicators (Latifah, 2023).

Table 8. Results of the Normality Test of the Pre-test and Post-test of Critical Thinking assisted AI

Department	**Class**	**Shapiro-Wilk**		
		N	**Statistic**	**Sig**
Biology Education	Class A	30	0.970	0.292
Biology Education	Class B	30	0.964	0.212

Based on the statistical results of the Shapiro–Wilk normality test, both classes show significance values greater than 0.05 (Class A = 0.292; Class B = 0.212), indicating that the data are normally distributed. This result confirms that the improvement in students' critical thinking skills after the implementation of the ICARE-Modification model can be analyzed using parametric statistical approaches, and it also supports the validity of the observed learning outcomes. The normal distribution of the data suggests that the improvement in students' scores occurred consistently across participants rather than being influenced by extreme values (Sappaile et al., 2025).

The improvement in students' critical thinking skills can be theoretically explained through the learning processes embedded in the ICARE-Modification model, particularly the application and reflection stages. In the application stage, students actively engage in analyzing environmental cases, discussing possible solutions, and constructing arguments based on scientific information and evidence. This stage promotes strong cognitive engagement, as students must interpret data, evaluate information sources, and justify their reasoning when solving problems. Such learning activities are closely aligned with the principles of inquiry-based learning, where students develop knowledge through questioning, investigation, and problem-solving processes.

Meanwhile, the reflection stage encourages students to review the results of their discussions and reconsider the arguments they developed during the learning process. Through reflection, students evaluate the validity of their reasoning, compare different viewpoints, and identify possible weaknesses in their conclusions. This process supports argument evaluation and strengthens metacognitive processes, as students become more aware of their own thinking processes and learning strategies. From a theoretical perspective, these activities are consistent with the principles of constructivist learning theory, which emphasize that knowledge is actively constructed through experience, interaction, and reflection. Therefore, the structured learning activities in the ICARE-Modification model, particularly during the application and reflection stages, create opportunities for students to engage in inquiry, critical analysis, and self-evaluation, which ultimately contribute to the improvement of their critical thinking skills (Karim et al., 2024).

Table 9. Paired t-test of pretest and postest data on critical thinking assisted AI

Department	Class	Paired-Test		
		N	Statistic	Sig
Biology Education	Class A	30	-27.267	0.000
Biology Education	Class B			

Based on Table 9, the highest N-gain value was found in the aspect of analyzing observation results, with an N-gain value of 0.88, which is categorized as high. The aspect of questioning ability also shows an N-gain value of 0.93, which is categorized as very high, while the ability to make assumptions shows an N-gain value of 0.83, which is also categorized as very high. These results indicate that students experienced a shift in critical thinking skills from a low category toward moderate and high categories. Based on these findings, the integration of critical thinking skills into plant ecology learning can facilitate students' understanding of scientific concepts and help them recognize the importance of promoting sustainable living (Jusriana, 2024; Latifah, 2023; Rayanto & Supriyo, 2022). Furthermore, improving students' critical thinking skills can be more easily understood when integrated with real-life problems, cultural contexts, as well as social and life issues.

The average score of students' critical thinking competency increased from 24 to 84. The results of this study are also supported by (Mawaddah, 2024). The t-test results indicate that there is a significant difference in students' critical thinking skills before and after participating in learning using the ICARE-Modification model. AI-based learningis one of the factors that contribute to improving students' understanding of science concepts. Social interaction among students within groups during the learning process can enhance distributed cognitive learning and individual constructivism. When students share information, including the ability to make assumptions and respond to each other's ideas, they improve their understanding, elaborate their knowledge, become encouraged to clarify and organize ideas, and recognize weaknesses in their reasoning (Nyoman et al., 2025; Putra et al., 2024).

Ultimately, new perspectives and alternatives will emerge in accordance with the development of their thinking abilities. Students' critical thinking skills are formed through interactions between students and their environment (Primahesa et al., 2023; Putra et al., 2024; Setiawan et al., 2021). This is consistent with the findings of (Saputri & Nurlianti, 2022; Sumilat, 2025) which state that students' critical thinking skills related to plant ecology materials will improve through social interaction, questioning activities, and conducting observations in the surrounding environment (Ahman et al., 2025; Hidayati et al., 2025; Indah & Borneo, 2020) also found that contextual plant ecology learning integrated with students' critical thinking skills can improve questioning ability, the ability to analyze observation results, and the ability to make assumptions. Plant ecology learning is one way to understand and answer various questions about the world. Currently, plant ecology learning is no longer individual-based but provides greater benefits when developed through a community-based approach Klik atau ketuk di sini untuk memasukkan teks. Therefore, through learning activities that train students' critical thinking skills and AI-assisted e-learning, students are expected to develop awareness and concern for the environment. Thus, the ICARE-Modification model has a positive impact on improving students' critical thinking skills before and after participating in learning using the developed ICARE-Modification model.

CONCLUSION

Fundamental Finding: This study confirms that the ICARE-Modification model**,** which integrates structured inquiry stages with AI-assisted problem-solving activities, effectively improves undergraduate students' critical thinking skills. The instructional sequence—Introduction, Connection, Application-Modification, Reflection, and Extension—provides systematic cognitive scaffolding that facilitates questioning, analytical reasoning, evaluation, and solution formulation. The findings indicate that combining reflective learning processes with AI-supported tasks can significantly enhance higher-order thinking development among students in teacher education programs. **Implication**: The findings highlight important implications for higher education practice. Lecturers are encouraged to implement structured inquiry-based instructional approaches that explicitly support higher-order thinking development. The ICARE-Modification model offers a practical framework for integrating reflective learning, analytical reasoning, and AI-supported activities in classroom instruction. In addition, curriculum designers should incorporate reflective and evaluative components within course structures, while universities should provide professional development programs to support lecturers in designing AI-integrated pedagogical strategies aligned with 21st-century learning competencies. **Limitation**: This study has several limitations. The research was conducted with a relatively limited sample within a single teacher education program**,** which may restrict the generalizability of the findings. Furthermore, the study mainly assessed students' critical thinking skills through test-based instruments and did not comprehensively examine other influential factors such as students' metacognitive awareness, learning engagement, or technological readiness during AI-supported learning activities. **Future Research**: Future studies should conduct longitudinal investigations to examine the long-term development of students' critical thinking skills across multiple semesters. Expanding the sample to different universities and academic disciplines would also enhance the generalizability of the findings. Additionally, future research could explore the role of metacognitive awareness, cognitive engagement, and collaborative learning processes in AI-supported learning environments. Comparative studies examining different AI-integrated instructional models are also recommended to identify the most effective pedagogical strategies for fostering higher-order thinking skills in higher education.

REFERENCES

Ahman, E., Dahlan, D., & Supendra, D. (2025). *Identifying Key Factors Influencing the Development of Higher Order Thinking Skills (HOTS) in Students : A Systematic Literature Review*. *17*(2010), 5242–5257. https://doi.org/10.35445/alishlah.v17i3.6627

Anggraini, A. E., Subuatningsih, O. A., Khotimah, K., Kang, E., & Sufian, M. (2024). *Thematic Learning Tools Based on Collaborative Learning Models for Grade IV Elementary School*. *8*(4), 670–678.

Ariadila, S., Silalahi, Y., Fadiyah, F., Jamaludin, U., & Setiawan, S. (2023). *Analisis Pentingnya Keterampilan Berpikir Kritis Terhadap Pembelajaran Bagi Siswa*. *9*(20), 664–669. https://doi.org/https://doi.org/10.5281/zenodo.8436970

Elok, S., Fatkhi, S., & Solihah, M. (2023). *Integrative Science Education and Teaching Activity Journal Application of The Inquiry Based ICARE Learning Model Toward Cognitive Learning Outcomes on Salt Hydrolysis Material*. *4*(2), 231–244.

Endrawan, I. B., & Aliriad, H. (2023). *Problem-Based Collaborative Learning Model Improves Physical Education Learning Outcomes for Elementary School Students*. *11*(1), 9–17.

Gazali, F., & Dasna, I. W. (2023). *Edukatif : Jurnal Ilmu Pendidikan Meningkatkan Keterampilan Berpikir Kritis Siswa dalam Pembelajaran Kimia : Sebuah Studi Literatur*. *5*(3), 1403–1414.

Hidayati, A., Hidayat, H., Ardi, Z., Rahmi, U., & Saputra, A. (2025). *Enhancing Higher Order Thinking Skill (HOTS) through Student Engagement and Learning Support*. *15*(9), 1842–1852. https://doi.org/10.18178/ijiet.2025.15.9.2385

Ibtidaiyah, M. (2024). *ANALISIS MODEL CRITICAL THINKING PADA KONTEN FIKIH DI MADRASAH IBTIDAIYAH Hikmatu Ruwaida STIQ Amuntai , Kalimantan Selatan , Indonesia Nida Mauizdati STIQ Amuntai , Kalimantan Selatan , Indonesia Abstrak Al-Madrasah : Jurnal Ilmiah Pendidikan Madrasah Ib*. *8*(1), 390–408. https://doi.org/10.35931/am.v8i1.2883

Indah, P., & Borneo, E. (2020). *Development of HOTS (High Order Thinking Skill) Increase The Critical Thinking Skill of High School*. *4*(April). https://doi.org/10.20885/ijcer.vol

Jatiningsih, O. (2025). *High Order Thinking Skills (HOTS) Analysis of Grade VIII Junior High School Students on the Subject of Preserving My Nation ' s Culture*. *3*(4), 1–16.

Jusriana, A. (2024). *The Effect of ICARE Learning Model on Students ' Learning Outcomes in Physics Learning Class XI SMAN 13 Makassar*. *1*(3), 65–69.

Karim, M., Syafrul Antoni, & Karlini Oktarina. (2024). Meta-Analysis of Collaborative Learning Approaches in Educational Management and Their Impact on Student Performance. *Indonesia Journal of Engineering and Education Technology (IJEET)*, *2*(2), 427–434. https://doi.org/10.61991/ijeet.v2i2.85

Karmila, W., Achmad, S., & Utami, U. (2023). *High-Order Questions Improve Students ' Critical Thinking Skills In Elementary Schools*. *7*(2), 196–203.

Latifa, A., Nur, R., & Rizal, A. (2020). *ICARE Learning Model in Improving the Students Writing Ability*. *4*(2), 258–269.

Latifah, A. (2023). *COLLABORATIVE LEARNING IN THE DIGITAL ERA : STRATEGIES TO PREPARE PRIMARY SCHOOL STUDENTS TO FACE THE CHALLENGES OF THE 21ST CENTURY*. *7*(1), 67–76.

Mardliyah, S. Z., Salsabilla, A. P., Luthfi, N., & Herianingtyas, R. (2023). *STRATEGI PENINGKATAN KEMAMPUAN BERPIKIR KRITIS*. *6*.

Mawaddah, F. (2024). *Development of E-Modules Based on the ICARE Learning Model to Improve*

Students ' Creative Thinking and Scientific Communication Skills. *10*(7), 4397–4403. https://doi.org/10.29303/jppipa.v10i7.7747

Melawati, Y., & Rosidin, U. (2023). *International Journal of Current Science Research and Review Development of A Higher-Order Thinking Skills (HOTS) Instrument to Measure Student ' s Critical Thinking Abilities in Class V Elementary School*. *06*(12), 8170–8176. https://doi.org/10.47191/ijcsrr/V6-i12-70

Mimhamimdala, F., & Nirwana, H. (2023). *Populer Learning Theory : Collaborative Learning*. *1*(2), 292–302.

Moreira-Choez, J. S., Lamus de Rodríguez, T. M., Núñez-Naranjo, A. F., Sabando-García, Á. R., Reinoso-Ávalos, M. B., Olguín-Martínez, C. M., Nieves-Lizárraga, D. O., & Salazar-Echeagaray, J. E. (2025). Validation of a teaching model instrument for university education in Ecuador through an artificial intelligence algorithm. *Frontiers in Education*, *10*. https://doi.org/10.3389/feduc.2025.1473524

Mulyani, A. Y. (2022). *Pengembangan Critical Thinking Dalam Peningkatan Mutu Pendidikan di Indonesia*. *1*(1), 100–105. https://doi.org/10.54259/diajar.v1i1.226

Nadia, H. (2025). *Implementation of Collaborative Learning through Learning Communities to Improve Teacher Professional Competence*. *2*(1), 30–37.

Nikmah, F. K., Singgih, S., & Muhlisin, A. (2025). The Effectiveness of the Introduction, Connection, Application, Reflection, Extension (ICARE) Learning Model in Improving Higher Order Thinking Skills (HOTS) of Junior High School Students. *Paedagogia: Jurnal Pendidikan*, *14*(2), 223–240. https://doi.org/10.24239/pdg.vol14.iss2.982

Nisa, H., Isnaini, M., & Utami, L. S. (2023). *Collaborative Learning Effect on Improving Stu dents ' Creativity and Critical Thinking in the Independent Curriculum*. *15*, 4038–4048. https://doi.org/10.35445/alishlah.v15i3.3538

Norsaniyah, S., Jadid, U. N., Java, E., & Outcames, L. (2025). *Collaborative learning strategies to improve student learning outcomes*. *03*(01), 472–479.

Nyoman, N., Darmayanti, Y., Ngurah, G., & Agustika, S. (2025). *ICARE-Based Animated Video Learning Media on Data Presentation in Mathematics for Fourth Grade Elementary School Students*. *9*, 31–42.

Oktavianty, E., Tms, H., Sirait, J., & Supriadi, Y. (2020). *Physics Higher Order Thinking Skills Analysis : Motion at Secondary School*. 13103–13110.

Primahesa, A., Ramli, M., Education, B., Science, E., & Maret, U. S. (2023). *Improving higher order thinking skills in high school biology: A systematic review*. *16*(1), 206–218.

Putra, E. D., Pradana, P. H., & Triwahyuni, E. (2024). *Implementation of the Introduce Connect Apply Reflect Extend (ICARE) Model Learning Flow in developing online modules based on U-Learning Class LMS*. *9*(1), 1309–1321. https://doi.org/10.29303/jppipa.v10i3.7160

Putri, E., & Fatmawati, L. (2024). *Analysis of High Order Thinking Skills (HOTS) in Objective Test Questions for Science Learning Material in Fourth Grade Elementary School*. *3*(03), 137–144. https://doi.org/10.56741/ijlree.v3i03.624

Putri, S., Rosmiati, Sudarmano, M., Subaedah, & Nengsih, R. (2025). *PENERAPAN MODEL CRITICAL THINKING DALAM MENINGKATKAN HASIL BELAJAR MTs BHAYANGKARA TALLO MAKASSAR*. *10*.

Rahardhian, A. (2022). *Kajian Kemampuan Berpikir Kritis (Critical Thinking Skill) dari Sudut Pandang Filsafat*. *5*(2), 87–94.

Rahmadhani, Suci., Amiruddin Siahaan, I. J. (2022). *ANALISIS PENERAPAN MODEL PEMBELAJARAN ICARE UNTUK MENINGKATKAN KEMAMPUAN BERFIKIR KRITIS SISWA DI ERA PANDEMI COVID.19*. *April*, 239–245.

Rayanto, Y. H., & Supriyo. (2022). *The Effectiveness of ICARE Model on Micro Teaching Subjects through Hybrid Learning Class*. *1*(6), 929–938.

Roikha, Aliyatur., Fatimatul Khikmiyah, I. Z. (2023). *PENGEMBANGAN LEARNING MANAGEMENT SYSTEM BERBASIS MOODLE MODEL PEMBELAJARAN ICARE PADA MATERI ARITMETIKA SOSIAL*. *15*, 116–126.

Risda, D., Parsaoran, S., & Efendi, R. (2021). *EFEKTIVITAS MODEL ICARE UNTUK MENINGKATKAN KETERAMPILAN*. *7*, 193–198.

Sappaile, B. I., Mokay, M. M., Supendi, D., Smas, M. H., & Rais, R. (2025). *Analysis of the Effectiveness of Collaborative Learning in Enhancing Academic Achievement in Junior High Schools*. *04*(01), 225–231. https://doi.org/10.55299/ijere.v4i1.925

Saputra, E. E. (2026). *Integration of Computer-Based Learning Media and Problem-Based Learning Models to Develop Critical Thinking Abilities in Early Childhood*. *7*(1), 501–510.

Saputri, M., & Nurlianti, S. (2022). *The Effectiveness of ICARE Learning Model in Improving Students ' Critical Thinking Skills and Collaboration Skills*. *8*(3). https://doi.org/10.29303/jppipa.v8i3.1360

Setiawan, J., Sudrajat, A., & Kumalasari, D. (2021). *Development of higher order thinking skill assessment instruments in learning Indonesian history*. *10*(2). https://doi.org/10.11591/ijere.v10i2.20796

Shanzey, P. (2025). *The Effectiveness of Online Collaborative Learning through Digital Platforms in Enhancing Students ' Communication Skills*. *3*(3), 110–119.

Siahaan, P., Dewi, E., & Suhendi, E. (2020). Introduction, connection, application, reflection, and extension (ICARE) learning model: The impact on students' collaboration and communication skills. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *9*(1), 109. https://doi.org/10.24042/jipfalbiruni.v9i1.5547

Sumilat, J. M. (2025). *Differentiated Learning through ICARE Model to Improve Problem Solving Skills on the Material of Flat Shapes Area in Fifth Grade Elementary School* (Issue Iceste). Atlantis Press SARL. https://doi.org/10.2991/978-2-38476-489-1

Suparni. (2016). *Upaya meningkatkan kemampuan berpikir kritis mahasiswa menggunakan bahan ajar berbasis integrasi interkoneksi*. *3*(3), 40–58.

Suwarni, A., & Natsir, N. (2024). *The Effectiveness of Project-Based Collaborative Learning in Improving English Speaking Skills of High School Students*. *December*.

Usri, U., & Ikbal Salam, A. M. (2024). Evaluation of the Effectiveness of Collaborative Learning Design in Improving the Students' Critical Thinking Ability in West Sulawesi Universities. *International Journal of Economy, Education and Entrepreneurship (IJE3)*, *4*(3), 668–680. https://doi.org/10.53067/ije3.v4i3.307

Wardani, I. S., & Fiorintina, E. (2023). *Building Critical Thinking Skills of 21st Century Students through Problem Based Learning Model*. *12*(3), 461–470.

Zumrotus, D., Arnita, D., Mistika, H. P., & Sesba, H. K. (2025). *Pentingnya Critical Thinking dalam Menghadapi Tantangan Dunia Kerja dan Kehidupan Sehari-Hari*. *November*.

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