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Enhancing Students' Critical Thinking and Sustainability Awareness through the Concept Attainment Model–Education for Sustainable Development (CAM-ESD): A Quasi-Experimental Study in Indonesian Upper Secondary Biology

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ABSTRACT

Critical thinking skills and sustainability awareness are essential competencies for addressing global challenges in the 21st century. However, students in Indonesia still demonstrate relatively low levels of both competencies. This study examines the effect of the Concept Attainment Model (CAM) based on Education for Sustainable Development (ESD) on the improvement of students' critical thinking skills and sustainability awareness in ecosystem learning. A quasi-experimental design with a non-equivalent control group was employed, involving two tenth-grade classes at one public high school in East Lampung, Indonesia (experimental group, n = 28; control group, n = 29). Data were collected through pretests, posttests, and sustainability awareness questionnaires. Data were analyzed using normalized gain (N-gain), independent samples t-test, and effect size (Cohen's d). Results showed that the experimental class achieved higher improvement in critical thinking skills than the control class, with moderate N-gain values (0.47 vs 0.37) and a large effect size (d = 1.12. Sustainability awareness improved more substantially in the experimental group than in the control group, with emotional awareness achieving a high N-gain (0.89 vs 0.52), behavioral and attitude awareness showing moderate improvement (0.61 vs 0.27), and sustainability practice awareness demonstrating lower but still higher gains in the experimental class (0.51 vs 0.31. These results indicate that the integration of CAM with ESD effectively enhances both cognitive and affective domains of learning. The study highlights the potential of this approach for fostering competencies that are critical to sustainable education and suggests its application across various subjects and educational levels.

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INTRODUCTION

21st-century education is required to produce graduates not only with knowledge but also with critical thinking skills and an awareness of sustainability. Challenging global conditions, such as climate change, environmental degradation, and social inequality, require students to be able to analyze, evaluate, and make informed decisions when facing real-world problems. Therefore, learning must be directed at developing higher-order thinking skills while instilling sustainable values so that students can become agents of change in society (Cottrell, 2023; Dhiva Syabila, 2021; Dwyer et al., 2014). These skills are essential for analyzing information, evaluating alternative solutions, and making informed decisions to address real-world problems. However, global challenges such as environmental degradation, the energy crisis, and social inequality demand sustainability awareness, ensuring that the younger generation is not only academically intelligent but also concerned about the preservation of life (Amran et al., 2019; Dwyer et al., 2014, p. 21).

Thus, among the various competencies required in 21st-century education, critical thinking stands out as a foundational skill for enabling students to confront and navigate complex global and environmental problem. Critical thinking skills are fundamental competencies required for addressing and solving problems in daily life (Franco-Mariscal et al., 2024; Jonassen, 2010; Sultonova et al., 2025). Issues concerning global awareness and environmental challenges have increasingly become major concerns (Hite & Seitz, 2021; R. L. Singh & Singh, 2016). The enhancement of critical thinking skills is therefore essential to equip individuals with the capacity to analyze, comprehend, and respond effectively to complex environmental issues (Ardiansyah et al., 2024; Halpern, 2014; Miao & Nduneseokwu, 2025). However, critical thinking alone is insufficient to ensure responsible decision-making without a strong awareness of sustainability and environmental responsibility.

In this context, sustainability awareness emerges as a crucial complementary competency that supports the application of critical thinking in addressing global and environmental challengesTo address global awareness issues and environmental challenges, human resources must be equipped with diverse competencies and skills (Aberšek & Flogie, 2022). Among these, sustainability awareness serves as a key competency that strengthens critical thinking by fostering

individuals' concern for environmental degradation and the threats to its sustainability (Hnatyuk et al., 2024). Individuals with sustainability awareness are better prepared to confront future challenges, critically reflect on global issues, and engage in sustainable actions to preserve ecosystem balance and improve quality of life (Mochizuki & Bryan, 2015; Shutaleva, 2023; S. Singh & Agarwal, 2024). Nevertheless, students' critical thinking and sustainability awareness remain limited. However, empirical evidence indicates that students' levels of critical thinking and sustainability awareness remain relatively low, suggesting a gap between educational goals and learning outcomes.

This gap highlights the need for innovative learning models that can simultaneously promote critical thinking and sustainability awareness. One potential learning model is the Concept Attainment Model (CAM) based on Education for Sustainable Development (ESD). This model emphasizes the process of achieving concepts through classifying positive and negative examples, so that students are actively involved in building understanding. The integration of CAM with ESD principles not only develops critical thinking skills but also fosters sustainability awareness, which encompasses environmental concern, social responsibility, and ethical awareness. Thus, CAM-ESD serves a dual function as a strategy to strengthen the cognitive and affective aspects of learning.

Previous research has shown that the Concept Attainment Model (CAM) is effective in improving students' critical thinking skills through the process of classifying examples and non-examples and discovering concept attributes (Joyce et al., 2008; Joyce et al., 2014; Abrami et al., 2015). However, most of these studies still focus on the cognitive aspect and have not standardized the application of CAM with the Education for Sustainable Development (ESD) framework. On the other hand, research on ESD emphasizes the importance of developing students' awareness of desire, environmental care, and social responsibility, but tends to focus on the affective and value aspects, without systematically integrating them with concept-based learning models that can strengthen critical thinking skills (Amran et al., 2019; Mochizuki & Bryan, 2015; Howlett et al., 2016).

Furthermore, Only a few studies have examined the integration of the Concept Attainment Model with Education for Sustainable Development, and none have focused on critical thinking and sustainability awareness in Indonesian upper secondary biology. Previous studies, however, have demonstrated its potential. Munir (2017) reported that the application of the Concept

Attainment Model significantly improved students' critical thinking skills, as indicated by N-Gain results: the experimental class achieved a high category (0.74), while the control class was categorized as moderate (0.59). Accordingly, further research on the Concept Attainment Model based on Education for Sustainable Development is necessary to investigate its impact on students' critical thinking skills and sustainability awareness.

To date, there has been little empirical research integrating the Concept Attainment Model with the principles of Education for Sustainable Development as a unified learning approach, particularly in the context of biology learning in secondary schools. Therefore, this study fills this gap by examining the implementation of ESD-based CAM (CAM-ESD) which simultaneously aims to improve students' critical thinking skills and sustainability awareness. The novelty of this study lies in the integration of CAM and ESD which are tested simultaneously in two learning domains, namely cognitive and affective, thus providing a new empirical contribution to the development of sustainability-oriented learning models in science education.

The purpose of this study is to analyze the effect of CAM-ESD implementation on students' critical thinking skills and sustainability awareness. Furthermore, this study also aims to provide an overview of the learning model's effectiveness in establishing a balance between academic ability and sustainability awareness.

RESEARCH METHODS

This research employed a quasi-experimental approach using a pretest–posttest non-equivalent control group design. The experimental group was instructed using the Concept Attainment Model integrated with Education for Sustainable Development (CAM-ESD), while the control group engaged in discussion-based learning. The intervention was conducted over three instructional meetings, covering biology topics on ecosystem components, interactions among ecosystem components, energy flow, and ecological pyramids. Prior to the intervention, both groups completed a pretest, and following the completion of the instructional sessions, a posttest was administered using the same instrument.

The research population consisted of tenth-grade students at SMAN 1 Sekampung, East Lampung. Class X1 (28 students) was designated as the experimental group, while class X3 (29 students) served as the control group. The sampling technique applied was purposive sampling, as the population comprised classes with heterogeneous academic characteristics. Therefore, two classes were intentionally selected based on their relatively homogeneous levels of students'

academic ability, in order to ensure comparability between the experimental and control groups and to minimize potential bias in the research findings.

The instruments employed in this study consisted of tests and questionnaires. Critical thinking skills were assessed using 12 test items, while sustainability awareness was measured through a questionnaire comprising 15 Likert-scale statements. This research utilized quantitative data exclusively. Quantitative data were obtained from pretest and posttest scores measuring students' critical thinking skills on ecosystem-related content, as well as from numerical scores derived from the Likert-scale questionnaire assessing students' sustainability awareness. This research instrument was developed based on a theoretical foundation relevant to the research objectives. The critical thinking skills instrument refers to a critical thinking framework that includes indicators of basic clarification, the basis of a decision, inference, initial clarification, and strategies and tactics, which emphasize the ability to analyze information, develop arguments, and draw logical conclusions. Meanwhile, the awareness of desire instrument was developed based on the concept of Education for Sustainable Development (ESD) which includes three main dimensions, namely emotional awareness, behavioral and attitudinal awareness, and awareness of sustainability practices, to represent the affective and behavioral aspects of students towards sustainable issues.

The instrument development process begins with accounting for the research objectives into these theoretical indicators, then each indicator is translated into questions and statements relevant to the context of ecosystem learning and the implementation of CAM-ESD. To ensure alignment between the instrument and the research objectives, all items were validated by experts through content validity tests, so that each item is declared suitable for use in measuring the improvement of critical thinking skills and awareness of students' desires in accordance with the research focus. Both quantitative and qualitative data were utilized in the research. Quantitative data were derived from pretest and posttest scores assessing critical thinking skills on ecosystem-related content, while qualitative data were gathered from Likert-scale questionnaires addressing sustainability awareness and students' responses. Data analysis included validity test, normality and homogeneity test, independent sample t-test, N-Gain, and effect size analysis. The expert validity of the instruments was analyzed using percentage analysis, with the criteria presented in the Table 1.

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Table 1. Validity Test Criteria

Persentase	Validity Criteria
80 < V ≤ 100	Very High
60 < V ≤ 80	High
40 < V ≤ 60	Moderate
20 < V ≤ 40	Low
0 < V ≤ 20	Very Low

(Arikunto, 2009)

Based on the validity test results, 12 items were declared valid and feasible to be used as instruments in the study. The results of the validity test are presented in Table 2.

Table 2. Expert Validation Test Results of the Instrument

Question Number	Validity (%)	Category
1	84.5	Highly Valid
2	82.5	Highly Valid
3	84.5	Highly Valid
4	86.5	Highly Valid
5	82.5	Highly Valid
6	84.5	Highly Valid
7	86.5	Highly Valid
8	84.5	Highly Valid
9	82.5	Highly Valid
10	86.5	Highly Valid
11	84.5	Highly Valid
12	82.5	Highly Valid

After the instrument test, the research continued with data processing and analysis. The pretest and posttest scores for critical thinking skills, as well as the pre-questionnaire and post-questionnaire scores for sustainability awareness, were calculated using the following formula:

$$\overline{x} = \frac{x_i}{n} \times 100$$

Description:
x_i = total score obtained
n = maximum score

The Normalized Gain (N-Gain) was calculated using the formula:

$$N - Gain = \frac{X - Y}{Z - Y}$$

Description:
X = posttest or post-questionnaire score
Y = pretest or pre-questionnaire score
Z = maximum score

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The N-Gain values are interpreted to assess the improvement in students' learning outcomes and sustainability awareness. The criteria used to interpret the N-Gain values are as follows Table 3.

Table 3. N-Gain Score Criteria

N-Gain Score Category	Category
N-gain ≥ 0,7	High
0,3 ≤ N-gain < 0,7	Moderate
N-gain < 0,3	Low

(Hake, 2002)

Before testing the hypothesis, the data were first analyzed using SPSS for normality and homogeneity tests. The normality test aimed to ensure that the data were normally distributed, while the homogeneity test ensured that the variances between samples were equal. Once the data met these assumptions, hypothesis testing was conducted using an independent sample t-test; if the data were not normally distributed or not homogeneous, the Mann-Whitney test was employed. The magnitude of the treatment effect was calculated using effect size (Cohen's d), with the following interpretation as presented in Table 4.

Table 4. Criteria for interpreting effect size values

Effect size	Effectiveness Interpretation
0 – 0.20	Very Low
0.21 – 0.50	Low
0.51 – 1.00	Moderate
> 1.00	High

(Cohen, et al.,1988)

This research was carried out in accordance with ethical standards for educational research. Approval was obtained from the school authorities prior to data collection. Informed consent was also obtained from all participating students and their guardians. Participants were informed about the purpose of the study, the voluntary nature of their participation, and the confidentiality of their responses.

RESEARCH RESULT

Critical Thinking

Data processing and analysis in this study were carried out using IBM SPSS Statistics Version 25 on pretest, posttest, and N-Gain scores. The data were analyzed through normality test, homogeneity test, and independent sample t-test. The results of N-Gain calculation are presented in Table 5. Table 5 shows that the mean scores of pretest, posttest, and N-Gain in the

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experimental class are higher than in the control class. The N-Gain in the experimental class was 0.47 (moderate), while in the control class it was 0.37 (moderate).

Table 5. Normalized-Gain (N-Gain) Scores of Students' Critical Thinking Skills

Class	Test	$\bar{x}$ ±Sd	$\bar{x}$ *N-Gain*	Interprestation	Category
Experimental Class	*Pretest*	40,69 ± 4,17	0,47	0,3 ≤ *N-gain* < 0,7	moderate
	Posttest	68,81 ± 3,85			
Control Class	*Pretest*	37,76 ± 4,70	0,37	0,3 ≤ *N-gain* < 0,7	moderate
	Posttest	61,20 ± 3,48			

Based on Table 5, the results of the normality and homogeneity tests indicate that the data from the experimental and control classes meet the assumptions required for parametric statistical analysis. The normality test shows that the data distribution in both groups is approximately normal, while the homogeneity test confirms that the variances are equal, indicating that the data are consistent and comparable across the two classes. An independent sample t-test was then conducted to examine whether there is a statistically significant difference in the improvement of students' critical thinking skills between the groups. The t-test yielded a significance value of 0.000 (Sig. 2-tailed < 0.05), indicating that the improvement in critical thinking skills in the experimental class is significantly greater than in the control class, confirming that the intervention had a meaningful impact compared to conventional instruction.

Table 6. Statistical Test of Critical Thinking Skills

Class	**$\bar{x}$ N-Gain ±Sd**	**Normality Test**	**Homogeneity Test**	**Independet Sample t-Test**
Experimental Class	0.47 ± 0.04	Sig. 0.88 > 0.05	Sig 0.58 > 0.05	Sig (2-tailed) 0.000 < 0.05 (H1 Accepted)
Control Class	0.37 ± 0.06	Sig. 0.98 > 0.05		

Table 6 shows that all critical thinking indicators in the experimental class improved after the implementation of the Concept Attainment Model based on Education for Sustainable Development (CAM-ESD), with N-Gain values ranging from moderate to high. The Inference indicator experienced the highest increase, reaching a high category, while other indicators such as Strategic and Tactic, Bases for a Decision, and Advance Clarification showed moderate improvements. In contrast, in the control class, most indicators only reached the low to moderate category, with the Basic Clarification indicator classified as low. These results suggest that CAM-ESD was more effective in enhancing students' critical thinking skills across multiple dimensions compared to conventional teaching methods (Table 7).

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Table 7. Average Scores of Critical Thinking Skills Indicators in the Experimental and Control Classes

Indicator	Class	Mean		Difference	N-Gain	Category
		Pretest	Posttest			
Basic clarification	E	40.20	61.03	0.06	0.35	Moderate
	K	39.22	57.11		0.29	Low
Bases for a decision	E	51.47	72.06	0.01	0.42	Moderate
	K	40.44	64.71		0.41	Moderate
Inference	E	36.27	80.64	0.37	0.70	High
	K	32.60	54.66		0.33	Moderate
Advance clarification	E	33.82	58.46	-0.03	0.37	Moderate
	K	34.93	61.03		0.40	Moderate
Strategic and tactic	E	35.29	63.97	0.02	0.44	Moderate
	K	29.41	58.82		0.42	Moderate
Average					0.41	Moderate

Table 8 shows the results of the effect size analysis for students' critical thinking skills. The experimental class achieved an effect size of 1.12, which falls into the high category, indicating that the intervention had a substantial impact on enhancing students' critical thinking abilities. In contrast, the effect size in the control class was lower, suggesting that conventional teaching methods had a comparatively smaller effect. These results confirm that the Concept Attainment Model based on Education for Sustainable Development (CAM-ESD) significantly contributed to improving students' critical thinking skills.

Table 8. Results of Effect Size Analysis

Class	Average	Standard Deviation	Effect size	Category
Eksperimental Class	0.47	0.04	1.12	High
Control Class	0.37	0.06		

The results indicate that the treatment given in the experimental class was more effective in improving students' critical thinking skills than in the control class. The highest improvement occurred in the Inference indicator, whereas the Advance Clarification indicator was higher in the control class, as the discussion method provided greater opportunities for evaluating arguments critically. Basic Clarification and Bases for a Decision indicators in the experimental class showed significant improvement, consistent with the characteristics of the Concept Attainment Model (CAM) based on Education for Sustainable Development (ESD). The Strategic and Tactic indicator in the experimental class was slightly higher than in the control class, reflecting students' ability to design both long-term strategies and practical steps more systematically. The calculation

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of effect size (Cohen's d) confirmed that CAM based on ESD had a significant effect on improving critical thinking skills.

Sustainability Awareness

The sustainability awareness questionnaire used in this study consisted of 15 closed-ended statements developed based on three main indicators: Sustainability Practice Awareness, Behavioral and Attitude Awareness, and Emotional Awareness. Table 9 presents the average scores for each indicator in both the experimental and control classes.

Table 9. Average Scores per Sustainability Awareness Indicator in the Experimental and Control Classes

Indicator	Eksperimental Class			Control Class		
	Pre-questionnaire	Post-questionnaire	N-Gain	Pre-questionnaire	Post-questionnaire	N-Gain
Emotional Awareness	44.11	94.11	0.89	50.30	76.36	0.52
Behavior and Attitude Awareness	22.94	70.58	0.61	24.24	44.84	0.27
Sustainability Practice Awareness	12.94	57.64	051	25.45	47.87	031

Based on the comparison of N-Gain values for each sustainability awareness indicator, the experimental class consistently demonstrated higher improvement than the control class across all indicators. The highest N-Gain in the experimental group was observed in emotional awareness, indicating that the CAM-ESD learning approach was particularly effective in fostering students' emotional sensitivity toward environmental and sustainability issues. Substantial gains were also evident in behavior and attitude awareness as well as sustainability practice awareness, suggesting that students not only developed cognitive understanding but also showed increased readiness to adopt sustainable behaviors. In contrast, although the control class exhibited improvement in all indicators, the N-Gain values were comparatively lower, reflecting more limited learning gains through discussion-based instruction.

Overall, these findings indicate that the integration of the Concept Attainment Model with Education for Sustainable Development provides a more effective learning environment for enhancing multiple dimensions of students' sustainability awareness compared to conventional instructional approaches suggesting that while students demonstrated some understanding of sustainable practices, their application of this knowledge in real-life situations remained relatively limited (Barrón et al., 2022; Deniz, 2016). In the control class, the pattern was similar in that the highest difference between pre- and post-questionnaire scores was also found in Emotional Awareness, whereas the lowest difference appeared in the Behavioral and Attitude Awareness

indicator. Taken together, these findings suggest that the overall increase in sustainability awareness was markedly higher in the experimental class than in the control class, demonstrating the effectiveness of the intervention.

DISCUSSION

The Concept Achievement Model Based on Sustainable Development Education (CAM-ESD) is a learning strategy that integrates systematic thinking through the identification of examples and non-examples related to real-life sustainable development issues. Through this model, students not only learn theoretical concepts but are also challenged to analyze sustainability issues relevant to their daily lives. The process of differentiating, generalizing, and discovering the attributes of these concepts provides a strong foundation for developing students' critical thinking skills (Abrami et al., 2015; Kettler, 2021).

The results showed that students in the experimental class achieved higher N-Gain scores in overall critical thinking skills than those in the control class. Notably, the inference indicator demonstrated the highest N-Gain, indicating that CAM-ESD particularly strengthens students' ability to draw conclusions from evidence and observed patterns**.** In practice, CAM-ESD exposes students to real-world phenomena, such as the differences between environmentally friendly practices and those that damage the environment. This activity encourages them to test assumptions, weigh evidence, and draw logical conclusions(Cottrell, 2023; Gambrill, 2006; Silver et al., 2012). Thus, CAM-ESD fosters critical thinking habits through contextualized learning based on issues close to their realities. The use of CAM-ESD also emphasizes the process of reflection. Students are not only asked to identify correct concepts but also to reflect on the environmental, social, and economic impacts of an action (Fisher & McAdams, 2015; Schaltegger & Burritt, 2017). This reflection demands critical thinking skills in questioning cause and effect, evaluating consequences, and formulating more responsible decisions (Halpern, 2014; Khalifa, 2024; Pherson & Pherson, 2020). Through this reflective engagement, students learn that critical thinking does not stop at analysis but also extends to moral judgments and the sustainability of actions (Howlett et al., 2016; McPeck, 2016; Rieckmann, 2018).

Furthermore, CAM-ESD fosters critical communication skills among students. The discussion process of examples and non-examples stimulates argumentation, mutual reasoning, and the development of shared conclusions (B. Joyce et al., 2008; Pherson & Pherson, 2020; Spector, 2019). Through these interactions, students learn to defend opinions with logical

reasoning, listen to differing perspectives, and critique ideas constructively. This activity is crucial in developing collaborative and applicable critical thinking skills in a social context (Bean & Melzer, 2021; Hajhosseini et al., 2016; Sweet & Michaelsen, 2023).

Therefore, CAM-ESD positively impacts students' critical thinking skills because it combines systematic conceptual mastery with real-life sustainability issues. This model familiarizes students with analyzing information, evaluating arguments, drawing conclusions, and considering the long-term implications of decisions(Bean & Melzer, 2021; Kippers et al., 2018; Kumar et al., 2024). The integration of conceptual and sustainability learning makes CAM-ESD relevant as a 21st-century educational approach, producing not only cognitively intelligent students but also critical and concerned with sustainability.

The Concept Achievement Model Based on Sustainable Development Education (CAM-ESD) is a learning strategy that integrates concept acquisition techniques with sustainability issues. Through this approach, students learn to recognize the essential attributes of a concept by comparing examples and non-examples relevant to sustainable development (B. R. Joyce et al., 2014). This process makes students more sensitive to actions or phenomena that support or conflict with sustainability principles, thereby fostering awareness of the importance of maintaining environmental, social, and economic balance(Dalampira & Nastis, 2020; Howlett et al., 2016).

CAM-ESD provides a contextual learning experience because the concepts learned are directly linked to real-world situations. For example, students can be asked to differentiate between environmentally friendly waste management practices and those that pollute the environment (Kumar et al., 2024; Schaltegger & Burritt, 2017). In this way, they not only understand the abstract definition of sustainability but also recognize how the concept is present in everyday life. This awareness is the first step in developing sustainability awareness (Aberšek & Flogie, 2022; Barrón et al., 2022).

Furthermore, CAM-ESD engages students in a critical thinking process to assess whether an action is sustainable. This decision-making process encourages students to consider the long-term impacts of an action on the environment and society(Aminrad et al., 2013; Barrón et al., 2022). By becoming accustomed to conducting this type of analysis, students will develop a greater sensitivity in assessing their own and others' actions, thus strengthening their awareness of sustainability(Aminrad et al., 2013; Feijoo & Moreira, 2020).

Learning with CAM-ESD also provides space for students to discuss and reflect on sustainability values. . With respect to sustainability awareness, the experimental class showed greater improvement across all indicators compared to the control class. The emotional awareness indicator achieved the highest N-Gain, indicating that CAM-ESD effectively enhances students' sensitivity and concern toward environmental issues. As they compare examples and non-examples, students can debate, reason, and test differing perspectives. This reflective activity helps them internalize sustainability principles, not only as knowledge but also as a life attitude that guides concrete actions in the future (Aberšek & Flogie, 2022; Ahmad et al., 2015; Amran et al., 2019). Thus, CAM-ESD influences students' sustainability awareness by connecting academic concepts with the realities of life that demand sustainability. Students not only understand the concepts intellectually but also recognize their role in maintaining environmental sustainability, social justice, and economic prosperity. This awareness is crucial for developing a more responsible generation prepared to face global challenges with sustainability-oriented actions(Adha et al., 2019; de la Vega, 2004; Feijoo & Moreira, 2020).

This research has significant theoretical and practical implications in the context of science education. Theoretically, the findings of this study strengthen the constructivist learning framework by demonstrating that the integration of the Concept Attainment Model and Education for Sustainable Development (CAM-ESD) can systematically link the process of concept attainment with the development of critical thinking skills and sustainability awareness simultaneously, thereby broadening the understanding of the role of concept-based learning models in achieving sustainable education goals. Practically, the results of this study provide empirical evidence that CAM-ESD can be used as an alternative effective learning strategy for biology teachers to foster critical thinking skills while instilling sustainability values in ecosystem learning. This model can also be a reference for curriculum developers and educators in designing learning that is not only oriented towards mastery of material, but also on the formation of students' attitudes and awareness of sustainability issues, thereby supporting the achievement of 21st-century competencies and sustainable development goals.

The findings of this study have several important implications for educational practice and future research. For teachers, CAM-ESD can be implemented through the systematic design of learning activities that incorporate sustainability-related examples and non-examples, reflective questioning, and discussions of real-life environmental issues to promote meaningful learning. For

curriculum designers, these results underscore the importance of integrating Education for Sustainable Development (ESD) principles more explicitly within biology curricula, rather than treating sustainability as a supplementary topic. Furthermore, future research is encouraged to adopt longitudinal research designs, involve multiple schools, and examine the application of CAM-ESD across different subjects and educational levels to provide a more comprehensive understanding of its effectiveness

CONCLUSION

This study confirms that the integration of the Concept Attainment Model with Education for Sustainable Development (CAM-ESD) significantly enhances students' learning outcomes. Students in the experimental group demonstrated greater improvement in critical thinking skills, with the most prominent gains observed in the inference dimension, compared to those taught through discussion-based learning. In addition, CAM-ESD effectively improved students' sustainability awareness, particularly in the emotional awareness dimension, indicating increased sensitivity and concern toward environmental and sustainability issues. These findings suggest that CAM-ESD supports both cognitive development and affective engagement within biology learning. From an instructional perspective, the results highlight CAM-ESD as a promising approach for integrating higher-order thinking skills and sustainability values in science education, aligning with the goals of Education for Sustainable Development. However, this study was limited by its short implementation period and the use of a relatively small sample from a single school context. Future research is therefore recommended to involve longer instructional durations, broader participant populations, and diverse subject areas to further examine the effectiveness and scalability of CAM-ESD in promoting critical thinking and sustainability awareness.

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REFERENCE

Aberšek, B., & Flogie, A. (2022). *Human Awareness, Energy and Environmental Attitudes*. Springer International Publishing. https://doi.org/10.1007/978-3-031-05871-4

Abrami, P. C., Bernard, R. M., Borokhovski, E., Waddington, D. I., Wade, C. A., & Persson, T. (2015). Strategies for teaching students to think critically: A meta-analysis. *Review of Educational Research*, *85*(2), 275–314. https://doi.org/10.3102/0034654314551063

Adha, M. M., Budimansyah, D., Kartadinata, S., & Sundawa, D. (2019). Emerging volunteerism for Indonesian millennial generation: Volunteer participation and responsibility. *Journal of Human Behavior in the Social Environment*, *29*(4), 467–483. https://doi.org/10.1080/10911359.2018.1550459

Ahmad, J., Noor, S. M., & Ismail, N. (2015). Investigating students' environmental knowledge, attitude, practice and communication. *Asian Social Science*, *11*(16), 284. https://doi.org/10.5539/ass.v11n16p284

Aminrad, Z., Zakariya, S., Hadi, A. S., & Sakari, M. (2013). Relationship between awareness, knowledge and attitudes towards environmental education among secondary school students in Malaysia. *World Applied Sciences Journal*, *22*(9), 1326–1333.

Amran, A., Perkasa, M., Satriawan, M., Jasin, I., & Irwansyah, M. (2019). Assessing students 21 st century attitude and environmental awareness: Promoting education for sustainable development through science education. *Journal of Physics: Conference Series*, *1157*(2), 022025. https://doi.org/10.1088/1742-6596/1157/2/022025

Ardiansyah, A. I., Putra, A. K., & Nikitina, N. (2024). Investigating problem-based learning model's impact on student's critical thinking skills in environmental conservation context. *Jambura Geo Education Journal*, *5*(2), 87–103. https://doi.org/10.37905/jgej.v5i2.26110

Arikunto, S. (2009). *Dasar-dasar Evaluasi Pendidikan Ed. Revisi, Cet.9*. Bumi Aksara.

Barrón, N. G., Gruber, S., & Huffman, G. (2022). Student Engagement and Environmental Awareness. *Environmental Humanities*, *14*(1), 219–232. https://doi.org/10.1215/22011919-9481528

Bean, J. C., & Melzer, D. (2021). *Engaging ideas: The professor's guide to integrating writing, critical thinking, and active learning in the classroom*. John Wiley & Sons.

Cottrell, S. (2023). *Critical thinking skills: Effective analysis, argument and reflection*. Bloomsbury Publishing.

Dalampira, E.-S., & Nastis, S. A. (2020). Back to the future: Simplifying Sustainable Development Goals based on three pillars of sustainability. *International Journal of Sustainable Agricultural Management and Informatics*, *6*(3), 226–240. https://doi.org/10.1504/IJSAMI.2020.112089

de la Vega, E. L. (2004). *Awareness, knowledge, and attitude about environmental education: Responses from environmental specialists, high school instructors, students, and parents*. University of Central Florida.

Deniz, D. (2016). Sustainable thinking and environmental awareness through design education. *Procedia Environmental Sciences*, *34*, 70–79. https://doi.org/10.1016/j.proenv.2016.04.008

Dhiva Syabila, R. (2021, November). *Lack of Literacy and Critical Thinking Ability in Indonesia Society*.

Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, *12*, 43–52. https://doi.org/10.1016/j.tsc.2013.12.004

Feijoo, G., & Moreira, M. T. (2020). Fostering environmental awareness towards responsible food consumption and reduced food waste in chemical engineering students. *Education for Chemical Engineers*, *33*, 27–35. https://doi.org/10.1016/j.ece.2020.07.003

Fisher, P. B., & McAdams, E. (2015). Gaps in sustainability education: The impact of higher education coursework on perceptions of sustainability. *International Journal of Sustainability in Higher Education*, *16*(4), 407–423. https://doi.org/10.1108/IJSHE-08-2013-0106

Franco-Mariscal, A. J., Cano-Iglesias, M. J., España-Ramos, E., & Blanco-López, Á. (2024). The ENCIC-CT model for the development of critical thinking. In *Critical thinking in science education and teacher training* (pp. 3–42). Springer.

Gambrill, E. (2006). *Critical thinking in clinical practice: Improving the quality of judgments and decisions*. John Wiley & Sons.

Hajhosseini, M., Zandi, S., Hosseini Shabanan, S., & Madani, Y. (2016). Critical thinking and social interaction in active learning: A conceptual analysis of class discussion from Iranian students' perspective. *Cogent Education*, *3*(1), 1175051. https://doi.org/10.1080/2331186X.2016.1175051

Hake, R. R. (2002). Relationship of individual student normalized learning gains in mechanics with gender, high-school physics, and pretest scores on mathematics and spatial visualization. *Physics Education Research Conference*, *8*(1), 1–14.

Halpern, D. F. (2014). *Critical thinking across the curriculum: A brief edition of thought & knowledge*. Routledge.

Hite, K. A., & Seitz, J. L. (2021). *Global issues: An introduction*. John Wiley & Sons.

Hnatyuk, V., Pshenychna, N., Kara, S., Kolodii, V., & Yaroshchuk, L. (2024). Education's role in fostering environmental awareness and advancing sustainable development within a holistic framework. *Multidisciplinary Reviews*, *7*. https://doi.org/10.31893/multirev.2024spe012

Howlett, C., Ferreira, J.-A., & Blomfield, J. (2016). Teaching sustainable development in higher education: Building critical, reflective thinkers through an interdisciplinary approach. *International Journal of Sustainability in Higher Education*, *17*(3), 305–321. https://doi.org/10.1108/IJSHE-07-2014-0102

Jonassen, D. H. (2010). *Learning to solve problems: A handbook for designing problem-solving learning environments*. Routledge.

Joyce, B., Calhoun, E., & Hopkins, D. (2008). *Models of learning, tools for teaching*. McGraw-Hill Education (UK).

Joyce, B. R., Weil, M., & Calhoun, E. (2014). *Models of teaching*. Pearson Education Inc.

Kettler, T. (2021). A differentiated approach to critical thinking in curriculum design. In *Modern curriculum for gifted and advanced academic students* (pp. 91–110). Routledge.

Khalifa, O. (2024). *A Guidebook for Mastering Critical Thinking Skills: Sharpen Your Mind*. Othman Khalifa.

Kippers, W. B., Wolterinck, C. H. D., Schildkamp, K., Poortman, C. L., & Visscher, A. J. (2018). Teachers' views on the use of assessment for learning and data-based decision making in classroom practice. *Teaching and Teacher Education*, *75*, 199–213. https://doi.org/10.1016/j.tate.2018.06.015

Kumar, V., Choudhary, S. K., & Singh, R. (2024). Environmental socio-scientific issues as contexts in developing scientific literacy in science education: A systematic literature review. *Social Sciences & Humanities Open*, *9*, 100765. https://doi.org/10.1016/j.ssaho.2023.100765

McPeck, J. E. (2016). *Critical thinking and education*. Routledge.

Miao, Q., & Nduneseokwu, C. (2025). Advancing environmental leadership: Education, development, and training. *Environmental Leadership in a VUCA Era: An Interdisciplinary Handbook*, 467–538.

Mochizuki, Y., & Bryan, A. (2015). Climate change education in the context of education for sustainable development: Rationale and principles. *Journal of Education for Sustainable Development*, *9*(1), 4–26. https://doi.org/10.1177/0973408215569109

Pherson, K. H., & Pherson, R. H. (2020). *Critical thinking for strategic intelligence*. Cq Press.

Rieckmann, M. (2018). Learning to transform the world: Key competencies in Education for Sustainable Development. *Issues and Trends in Education for Sustainable Development*, *39*(1), 39–59.

Schaltegger, S., & Burritt, R. (2017). *Contemporary environmental accounting: Issues, concepts and practice*. Routledge.

Shutaleva, A. (2023). Ecological culture and critical thinking: Building of a sustainable future. *Sustainability*, *15*(18), 13492. https://doi.org/10.3390/su151813492

Silver, H. F., Dewing, R. T., & Perini, M. J. (2012). *Inference: Teaching students to develop hypotheses, evaluate evidence, and draw logical conclusions*. ASCD.

Singh, R. L., & Singh, P. K. (2016). Global environmental problems. In *Principles and applications of environmental biotechnology for a sustainable future* (pp. 13–41). Springer.

Singh, S., & Agarwal, S. (2024). Empowering individuals for a sustainable tomorrow: Role of life skills development. *Journal of Ecophysiology and Occupational Health*, *24*(2), 211–219. https://doi.org/10.18311/jeoh/2024/35800

Spector, J. M. (2019). Fostering Inquiry, Reasoning and Critical Thinking. In *Seeking Understanding* (pp. 229–243). Brill.

Sultonova, M. B., Ubaydullaeva, M. H. Q., & Abdullaeva, R. A. Q. (2025). Critical Thinking in Everyday Problem Solving. *Analysis of World Scientific Views*, *3*(5), 11–17.

Sweet, M., & Michaelsen, L. K. (2023). *Team-based learning in the social sciences and humanities: Group work that works to generate critical thinking and engagement*. Taylor & Francis.