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Article

The Effect of STEAM Oriented Inquiry Based Learning Model on Critical Thinking Skills and Cognitive Learning Outcomes on Biodiversity

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ABSTRACT

This study investigated the effect of the STEAM-oriented Inquiry Based Learning (IBL) model on students' critical thinking skills and cognitive learning outcomes in biodiversity topics among tenth-grade students at SMA Laboratorium UM. The study employed a quasi-experimental design using a Nonequivalent Control Group Design and involved 102 students divided into three groups: a STEAM-oriented IBL class, an IBL class, and a conventional learning class. Data were collected through tests measuring critical thinking skills and cognitive learning outcomes. The analysis techniques included ANCOVA, Bonferroni post hoc tests, and N-Gain analysis. The findings showed that the STEAM-oriented IBL model significantly influenced students' critical thinking skills and cognitive learning outcomes, with significance values of $p < 0.001$. The effect sizes were high, with η^2 values of 0.734 for critical thinking skills and 0.742 for cognitive learning outcomes. Furthermore, the N-Gain analysis indicated substantial improvement in both variables, with scores of 0.9 for critical thinking skills and 0.8 for cognitive learning outcomes. Overall, the STEAM-oriented IBL model proved more effective than the IBL and conventional models in improving students' higher-order thinking skills and academic achievement in biodiversity learning. The implementation of STEAM elements within the Inquiry Based Learning process encouraged students to participate actively in problem solving, investigation, collaboration, and knowledge construction. This approach also provided learning experiences that supported conceptual understanding and strengthened students' ability to analyze, evaluate, and interpret biological concepts in real-life contexts. Therefore, the STEAM-oriented IBL model can be considered an effective and innovative learning strategy for secondary biology education.

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INTRODUCTION

The demands of the 21st century require students to possess various essential skills in order to develop into competent and competitive individuals in the future (Hasriana et al., 2024). These skills include critical thinking, creativity, communication, collaboration, and problem-

solving abilities, which are important components of modern learning. In line with constructivist theory, the learning process should provide opportunities for students to construct knowledge through direct experiences and active engagement in learning. Therefore, education should be designed through student-centered and contextual learning that encourages active student participation in knowledge construction (Sonia et al., 2023). In this context, science learning, particularly Biology, plays a strategic role in integrating 21st-century skills into the educational process.

Biology is a branch of science that studies various life phenomena through systematic scientific processes. Biology learning not only emphasizes conceptual understanding but also the development of scientific thinking skills through observation, experimentation, data analysis, and conclusion drawing activities (Wedanthi & Dantes, 2025). This is in line with the Decree of the Head of BSKAP Number 046/H/KR/2025, which emphasizes the importance of implementing contextual and inquiry-based student-centered learning approaches in Biology education. Through these approaches, students are expected to understand concepts more deeply while developing critical thinking skills through scientific method stages, including identifying problems, formulating hypotheses, conducting investigations, analyzing data, and communicating findings (Ayu et al., 2025).

Critical thinking skills are among the most important competencies in Biology learning because students are required to analyze information, evaluate evidence, connect concepts, and solve real-life problems logically and systematically (Killpack et al., 2020). However, various studies have shown that students' critical thinking skills in Biology learning are still relatively low. Research by Marissa (2022) revealed that low Biology learning outcomes were influenced by learning models that had not optimally encouraged students' active involvement in concept discovery processes. Other studies also found that teacher-centered learning tends to make students passive and less trained in developing higher-order thinking skills (Herung et al., 2025). Similar conditions were identified through preliminary observations and interviews with Biology teachers at SMA Laboratorium UM. The observations indicated that students' critical thinking skills only reached 42%. In addition, in biodiversity material, approximately 25% of students had not achieved the minimum criteria for learning achievement (KKTP). These low learning outcomes indicate that students still experience difficulties in deeply understanding concepts, particularly in topics requiring observation, classification, and analysis of natural phenomena.

Biodiversity is one of the Biology topics that has contextual characteristics and is closely related to phenomena in the surrounding environment. This topic requires students to conduct direct observations, identify differences among living organisms, classify objects based on specific characteristics, and analyze relationships among ecosystem components (Simaremare, 2023). Therefore, learning in this topic requires instructional models that facilitate active investigation and concept discovery processes so that students not only memorize concepts but also understand them through meaningful learning experiences.

One learning model that can support this process is Inquiry-Based Learning (IBL). The IBL model emphasizes students' active involvement in investigation processes through observation, experimentation, data collection, and discussion activities to independently discover concepts (Diana & Febriyanti, 2025). Furthermore, the integration of the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach is considered capable of creating more contextual, creative, and interdisciplinary learning experiences because students are trained to integrate various disciplines in solving real-world problems (Prमितasari et al., 2024). Several previous studies have shown that the STEAM approach can improve creativity, science process skills, higher-order thinking skills, and students' learning motivation. Other studies also demonstrated that Inquiry-Based Learning effectively improves students' critical thinking skills and conceptual understanding through scientific investigation activities. Nevertheless, studies combining Inquiry-Based Learning with the STEAM approach in

biodiversity topics are still limited. Most previous studies have been conducted in general science topics or only focused on a single variable, such as creativity or science process skills. Therefore, the effect of STEAM-oriented Inquiry-Based Learning on critical thinking skills and cognitive learning outcomes in biodiversity topics has not been specifically investigated.

Currently, biodiversity learning at SMA Laboratorium UM has implemented the Problem-Based Learning (PBL) model. Although this model is designed to develop students' problem-solving skills, its implementation has not fully provided opportunities for students to directly engage in scientific discovery processes through observation, experimentation, and in-depth investigation activities (Putri et al., 2023). As a result, students' involvement in concept exploration processes remains relatively limited, causing the development of critical thinking skills and cognitive learning outcomes to be less than optimal. This condition indicates the need for learning innovations that not only focus on problem-solving but also facilitate inquiry processes and the integration of interdisciplinary knowledge more meaningfully.

Based on the explanation above, this study aims to analyze the effect of implementing STEAM-oriented Inquiry-Based Learning on students' critical thinking skills and cognitive learning outcomes in Grade X biodiversity material at SMA Laboratorium UM. The novelty of this study lies in the integration of Inquiry-Based Learning with the STEAM approach specifically in biodiversity material that emphasizes direct observation and investigation activities. This study also seeks to fill the research gap in previous studies, which remain limited in examining the combination of IBL and STEAM on both critical thinking skills and cognitive learning outcomes simultaneously in the context of Biology learning at the secondary school level.

METHODS

This study was conducted at SMA Laboratorium UM, located at Jalan Bromo No. 16, Kauman, Klojen District, Malang City, East Java 65119, during the first semester of the 2025/2026 academic year. The method used in this study was an experimental method aimed at examining causal relationships among variables through a quasi-experimental design in the form of a Nonequivalent Control Group Design. The research population consisted of all Grade X students of SMA Laboratorium UM in the 2025/2026 academic year, comprising ten classes. The research sample involved three classes with a total of 102 students selected in mid-October through an equivalence test using analysis of variance to determine the experimental class, positive control class, and negative control class. In its implementation, the experimental class received treatment in the form of STEAM-oriented Inquiry-Based Learning (IBL). Meanwhile, the positive control class used the Inquiry-Based Learning (IBL) model, whereas the negative control class implemented conventional learning through Problem-Based Learning (PBL). The study was conducted over one month with a total of four meetings. The research design used in this study is presented in Table 1.

Table 1. Research Design

Group	Pre-Test	Treatment	Post-Test
Experimental	O ₁	X ₁	O ₂
Positive Control	O ₃	X ₂	O ₄
Negative Control	O ₅	X ₀	O ₆

Source: Sugiyono (2021)

Notes:

X₁ = Treatment using STEAM-Oriented Inquiry-Based Learning

X₂ = Treatment using Inquiry-Based Learning

X₀ = Treatment using conventional learning

O₁, O₃, O₅ = Pre-Test

O₂, O₄, O₆ = Post-Test

Data collection in this study was conducted using test instruments and observation sheets. The measurement of critical thinking skills referred to the indicators proposed by Ennis (2013), while cognitive learning outcomes were developed based on the revised Bloom's taxonomy

indicators by Anderson and Krathwohl (2001). In addition, skill aspects were assessed through observations of students' activities during the learning process using observation sheets. A detailed description of the data collection techniques is presented in Table 2.

Table 2. Data Collection Techniques

Data	Aspect	Data Collection Technique	Data Collection Instrument
Critical Thinking Skills	Cognitive	Tests, structured assignments, and students' participation during the teaching and learning process	Pretest and posttest essay test sheets
Cognitive Learning Outcomes	Cognitive	Tests, structured assignments, and students' participation during the teaching and learning process	Pretest and posttest multiple-choice test sheets

Research instruments

The instruments used in this study included the Learning Objectives Flow (ATP), teaching modules, Student Worksheets (LKPD), and tests measuring students' critical thinking skills and cognitive learning outcomes. All instruments were developed based on the syntax of the STEAM-oriented Inquiry-Based Learning (IBL) model. To ensure data quality, validity, reliability, and item analysis tests were conducted. Instrument validity was assessed through expert judgment by biology education lecturers and senior high school Biology teachers on the ATP, teaching modules, LKPD, and essay test instruments (Arikunto, 2010).

Data analysis

Data analysis began with prerequisite tests, including the Shapiro–Wilk normality test and Levene's homogeneity test. After the data met the assumptions of normality and homogeneity ($\text{sig} > 0.05$), hypothesis testing was conducted using ANCOVA to examine the effect of STEAM-oriented Inquiry-Based Learning on students' critical thinking skills and cognitive learning outcomes at a 5% significance level (Sugiyono, 2021). Significant results were followed by a Bonferroni post hoc test using IBM SPSS Statistics version 16 to identify differences among treatment groups. In addition, a Normalized Gain (N-Gain) test was conducted to measure the improvement and effectiveness of learning based on normalized pretest and posttest score differences (Hake, 2001).

RESULTS AND DISCUSSION

Result

The research instruments were validated by lecturers and senior high school teachers, covering the Learning Objectives Flow (ATP), Student Worksheets (LKPD), teaching modules, and test instruments. The validation results indicated that all instruments were highly valid and reliable, with validity and reliability values exceeding the r-table value (0.396). Furthermore, prerequisite tests showed that the data were normally distributed and homogeneous, with significance values above 0.05, indicating that the data met the requirements for ANCOVA analysis.

Critical Thinking Skills Test Results

Critical thinking skills data were collected through pretest and posttest scores administered to the Positive Control Group (Inquiry-Based Learning), the Experimental Group (STEAM-oriented Inquiry-Based Learning), and the Negative Control Group (conventional learning). The data were analyzed by calculating mean scores, score differences, and percentage improvements before and after treatment, as presented in Table 3.

Table 3. Mean Scores, Differences, and Percentage of Improvement in Critical Thinking Skills

Group	Pretest	Posttest	Difference (Pre–Post)	Score Change	Percentage of Improvement (%)
Conventional Learning	51,62	59,06	7,43	0,14	14,40%
Inquiry-Based Learning	51,85	80,17	28,32	0,54	54,62%

Group	Pretest	Posttest	Difference (Pre-Post)	Score Change	Percentage of Improvement (%)
STEAM-Oriented Inquiry-Based Learning	51,26	95,02	43,76	0,85	85,37%

Based on Table 3, the pretest and posttest data on critical thinking skills are visualized in graphical form in Figure 1.

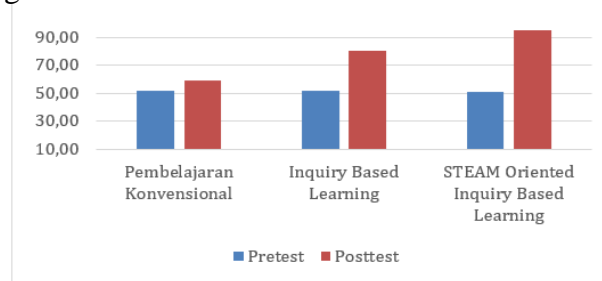


Figure 1. Pretest and Posttest Scores of Critical Thinking Skills

Students' critical thinking skills increased across all learning models. The conventional learning class showed an improvement of 14.40%, the Inquiry-Based Learning class increased by 54.62%, and the STEAM-oriented Inquiry-Based Learning class achieved the highest improvement of 85.37%. Detailed posttest mean scores for each critical thinking aspect are presented in Table 4.

Table 4. Average Posttest Scores for Each Aspect of Critical Thinking Skills in Each Group

Group	Aspect 1	Aspect 2	Aspect 3	Aspect 4	Aspect 5	Aspect 6
Conventional Learning	60,00 (Fair)	58,90 (Fair)	61,20 (Good)	62,50 (Good)	56,80 (Fair)	54,96 (Fair)
Inquiry Based Learning	81,20 (Excellent)	79,80 (Good)	80,00 (Good)	82,50 (Excellent)	78,90 (Good)	78,62 (Baik)
STEAM-Oriented Inquiry-Based Learning	94,50 (Excellent)	96,20 (Excellent)	95,80 (Excellent)	97,10 (Excellent)	93,90 (Excellent)	92,62 (Sangat Baik)

Notes:

- Aspect 1:** F (*Focus*)
- Aspect 2:** R (*Reason*)
- Aspect 3:** I (*Inference*)
- Aspect 4:** S (*Situation*)
- Aspect 5:** C (*Clarity*)
- Aspect 6:** O (*Overview*)

Category Criteria:

- Excellent (81–100)
- Good (61–80)
- Fair (41–60)
- Poor (≤ 40)

Based on Table 4, the STEAM-oriented Inquiry-Based Learning group achieved the highest average scores across all critical thinking aspects, categorized as "Excellent." These scores were higher than those of the Inquiry-Based Learning group, categorized as "Good" to "Excellent," and the Conventional Learning group, categorized as "Fair" to "Good." The critical thinking skills scores are further presented in Figure 2.

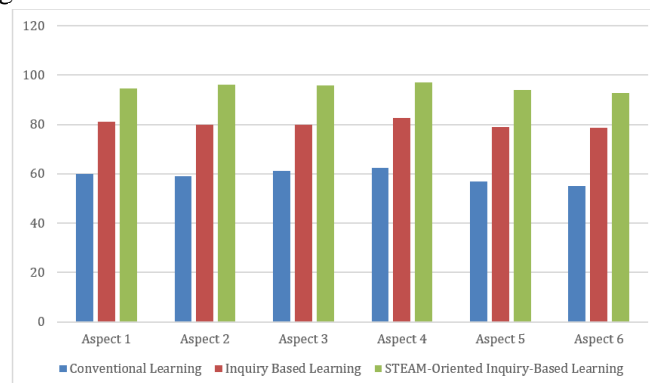


Figure 2. Average Posttest Scores of Critical Thinking Skills Aspects

The critical thinking skills data were further analyzed using Analysis of Covariance (ANCOVA) to determine the effect of implementing the STEAM-oriented Inquiry-Based Learning model on students' critical thinking skills. The results of the ANCOVA analysis regarding the effect of the learning model on critical thinking skills are presented in Table 5.

Table 5. Results of Analysis of Covariance (ANCOVA) for Critical Thinking Skills

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	11743.186a	3	3914.395	102.987	<.001	.756
Intercept	37224.553	1	37224.553	979.373	<.001	.912
PRETEST	153.731	1	153.731	4.045	.047	.041
MODEL	9964.458	2	4982.229	131.082	<.001	.734
Error	3610.814	95	38.009			
Total	664893.000	99				
Corrected Total	15354.000	98				

a. R Squared = .765 (Adjusted R Squared = .757)

- (i) PRETEST : F (1, 95) = 4.045; p < 0,05 (0,047); h2= 0,041
(ii) MODEL : F (2, 95) = 131.082; p < 0,05 (<0,001); h2= 0,734
(iii) Corrected Model : F (3, 95) = 102.987; p < 0,05 (<0,001); h2= 0,756

The null hypothesis (H_0) was rejected, indicating that the STEAM-oriented Inquiry-Based Learning model significantly affected students' critical thinking skills. ANCOVA results showed that pretest scores had a small but significant effect ($p = 0.047$; $\eta^2 = 0.041$), while the learning model had a significant effect with a large effect size ($p < 0.001$; $\eta^2 = 0.734$). The combined effect of prior ability and learning model was also significant ($p < 0.001$; $\eta^2 = 0.756$). The R Squared value of 0.765 indicated that 76.5% of the variation in critical thinking skills was explained by these variables. Therefore, a Bonferroni post hoc test was conducted to examine differences among groups.

Table 6. Bonferroni Post Hoc Test Results for Critical Thinking Skills

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.b	95% Confidence Interval for Difference b	
					Lower Bound	Upper Bound
STEAM-Oriented Inquiry-Based Learning	Inquiry Based Learning	16.507*	1.511	<0,001	12.825	20.189
	Conventional Learning	25.299*	1.598	<0,001	21.403	29.195
Inquiry Based Learning	STEAM-Oriented Inquiry-Based Learning	-16.507*	1.511	<0,001	-20.189	-12.825
	Conventional Learning	8.792*	1.550	<0,001	5.013	12.570
Conventional Learning	STEAM-Oriented Inquiry-Based Learning	-25.299*	1.598	<0,001	-29.195	-21.403
	Inquiry Based Learning	-8.792*	1.550	<0,001	-12.570	-5.013

The Bonferroni post hoc test results showed that students in the STEAM-oriented Inquiry-Based Learning group had significantly higher critical thinking skills than those in the Inquiry-Based Learning and Conventional Learning groups. The STEAM group's average score was 16.507 points higher than the Inquiry-Based Learning group and 25.299 points higher than the Conventional Learning group (Sig. < 0.001). Furthermore, the N-Gain test was conducted to measure the improvement and effectiveness of learning in biodiversity material, with the results presented in Table 7.

Table 7. N-Gain Calculation Results of Critical Thinking Skills in the Experimental Class

Pretest	Posttest	N-Gain	Category
49,38	93,97	0,9	High

Cognitive Learning Outcomes Test Results

The cognitive learning outcomes data were obtained from students' pretest and posttest scores in the Inquiry-Based Learning, STEAM-oriented Inquiry-Based Learning, and

Conventional Learning groups. The data were analyzed by calculating the mean scores, score differences, and percentage of improvement before and after treatment. The results are presented in Table 7.

Table 7. Mean Scores, Differences, and Percentage of Improvement in Cognitive Learning Outcomes

Group	Pretest	Posttest	Difference (Pre-Post)	Score Change	Percentage of Improvement (%)
Conventional Learning	50,46	60,78	10,31	0,20	20,43%
Inquiry-Based Learning	50,44	82,11	31,67	0,62	62,79%
STEAM-Oriented Inquiry-Based Learning	50,38	95,17	44,79	0,88	88,90%

Based on Table 7, the pretest and posttest data of cognitive learning outcomes are visualized in graphical form in Figure 3.

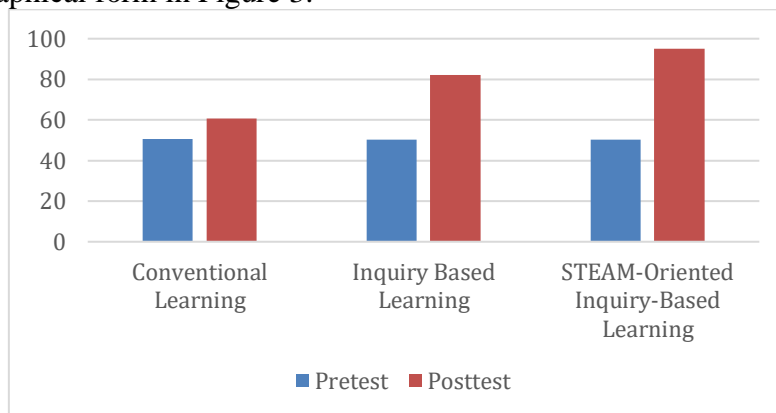


Figure 3. Mean Pretest and Posttest Scores of Cognitive Learning Outcomes

The cognitive learning outcomes data were subsequently analyzed using Analysis of Covariance (ANCOVA) to determine the effect of implementing the STEAM-oriented Inquiry-Based Learning model on cognitive learning outcomes. The results of the ANCOVA analysis of the effect of the learning model on cognitive learning outcomes are presented in Table 8.

Table 8. Results of Analysis of Covariance (ANCOVA) for Cognitive Learning Outcomes

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	12283.087a	3	4094.362	110.789	<0.001	0.778
Intercept	28800.669	1	28800.669	779.312	<0.001	0.891
PRETEST	172.603	1	172.603	4.670	0.033	0.047
MODEL	10088.484	2	5044.242	136.491	<0.001	0.742
Error	3510.873	95	36.957			
Total	668577.000	99				
Corrected Total	15793.960	98				

R Squared = .778 (Adjusted R Squared = .771)

- (i) PRETEST : F (1, 95) = 4.670; p < 0,05 (0.033); h2= 0.047
- (ii) MODEL : F (2, 95) = 136.491; p < 0,05 (<0.001); h2= 0.742
- (iii) Corrected Model : F (3, 95) = 110.789; p < 0,05 (<0.001); h2= 0.778

The null hypothesis (H_0), which stated that the STEAM-oriented Inquiry-Based Learning model had no effect on students' cognitive learning outcomes, was rejected. The ANCOVA results showed that pretest scores significantly influenced posttest cognitive learning outcomes ($p = 0.033$; $\eta^2 = 0.047$), indicating that students' prior abilities had a small effect on learning outcomes. In addition, the learning model significantly affected students' cognitive learning outcomes ($p < 0.001$) with a large effect size ($\eta^2 = 0.742$). The combined influence of prior

ability and learning model was also significant ($p < 0.001$) with a large effect size ($\eta^2 = 0.778$). The R Squared value of 0.778 indicates that 77.8% of the variation in students' cognitive learning outcomes was explained by prior ability and learning model variables, while 22.2% was influenced by other factors outside this study. Based on these findings, a Bonferroni post hoc test was conducted to identify differences among the treatment groups.

Table 9. Bonferroni Post Hoc Test Results for Cognitive Learning Outcomes

(I)	(J) Kelas	Mean Difference (I-J)	Std. Error	Sig.b	95% Confidence Interval for Difference b	
					Lower Bound	Upper Bound
Conventional Learning	Inquiry Based Learning	16.763*	1.493	<0,001	13.125	20.400
	Conventional Learning	25.717*	1.594	<0,001	21.834	29.601
	STEAM-Oriented Learning	-16.763*	1.493	<0,001	-20.400	-13.125
Inquiry Based Learning	Inquiry-Based Learning					
	Conventional Learning	8.955*	1.535	<0,001	5.214	12.696
STEAM-Oriented Learning	STEAM-Oriented Learning	-25.717*	1.594	<0,001	-29.601	-21.834
	Inquiry-Based Learning					
	Inquiry Based Learning	-8.955	1.535	<0,001	-12.696	-5.214

The results of the Bonferroni post hoc test presented in Table 14 show that there were significant differences in students' cognitive learning outcomes between the implementation of STEAM-oriented Inquiry-Based Learning and both Inquiry-Based Learning and conventional learning. The average score in the STEAM class was 16.763 points higher than the Inquiry-Based Learning class and 25.717 points higher than the conventional learning class, with a significance value of $p < 0.001$. After obtaining these significant differences, the analysis was continued using the N-Gain test to measure the extent of improvement in cognitive learning outcomes based on pretest and posttest scores, as well as to evaluate the effectiveness of learning in biodiversity material. The results of the N-Gain calculation in the class implementing STEAM-oriented Inquiry-Based Learning are presented in Table 10.

Table 10. N-Gain Calculation Results of Cognitive Learning Outcomes in the Experimental Group

Pretest	Posttest	N-Gain	Category
53,35	93,02	0,8	High

Discussion

Critical Thinking Skills

The results of data analysis using ANCOVA showed that STEAM-oriented Inquiry-Based Learning had a significant effect on improving students' critical thinking skills. The experimental class that implemented the STEAM-oriented Inquiry-Based Learning model showed an improvement of 85.37%, with a mean posttest score of 95.02. The significance value ($p < 0.001$) was lower than $\alpha = 0.05$, indicating that the STEAM-oriented Inquiry-Based Learning model significantly affected students' critical thinking skills, with an effect size (η^2) of 0.734, which falls into the category of a large effect on students' critical thinking skills (Cohen & Cohen, 2003). In the positive control class that implemented the Inquiry-Based Learning model and the negative control class that applied conventional learning, score improvements were observed but were not as optimal as those in the experimental class, with increases of 54.62% (mean posttest score = 80.17) and 14.40% (mean posttest score = 59.06), respectively.

Consistent with previous studies, the Inquiry-Based Learning model has generally been proven effective in helping students construct understanding through active involvement in the investigation process. According to El Ritli et al. (2022), Inquiry-Based Learning encourages students' active engagement in constructing and evaluating information so that learning does not occur passively. This engagement is reflected in investigative and problem-solving activities conducted independently or collaboratively, which contribute to the development of critical thinking skills through information processing and evidence-based conclusion drawing (Anugrah et al., 2025). Theoretically, these findings align with Jean Piaget's constructivist theory, which states that knowledge is actively constructed by students through experience and interaction with their environment. Bai et al. (2018), in their book *21st Century Skills Development Through Inquiry-Based Learning: From Theory to Practice*, also explained that inquiry-based learning can develop 21st-century skills, including critical thinking, through students' active participation in structured and meaningful inquiry processes. These findings are also supported by Roana et al. (2022), that inquiry-based laboratory activities significantly improved students' critical thinking skills through active investigation and scientific reasoning processes.

Several studies on STEAM-based learning also indicate that the integration of science, technology, engineering, arts, and mathematics can improve students' critical thinking skills. The STEAM approach is grounded in science and mathematics as disciplines oriented toward discovery and real-world problem solving through design and engineering approaches, thereby encouraging students to produce solutions that are both logical and creative (Barkah et al., 2024). The integration of art within STEAM serves as a balancing component that broadens students' ways of thinking, consistent with classical perspectives that position art as an important aspect in developing sensitivity and appreciation of beauty in education (Hadinugrahaningsih et al., 2017). Furthermore, the interdisciplinary, project-based, and real-world-oriented characteristics of STEAM strengthen students' cognitive engagement in constructing understanding and critically evaluating information (Henriksen, 2017). Yakman (2008), in *STEAM Education: An Overview of Creating a Model of Integrative Education*, theoretically explained that the STEAM approach encourages students to connect concepts across disciplines in a single problem-solving process, thereby developing their ability to analyze information, evaluate alternative solutions, and draw logical conclusions that directly support critical thinking development. Similarly, Chheun and Kong (2023) reported that scientific-method-based learning activities strengthened students' scientific attitudes and analytical thinking abilities through active participation in biology learning.

Differences in achievement across each critical thinking indicator among learning groups suggest that the characteristics of the learning model and its alignment with scientific thinking processes contributed to the outcomes obtained. In this study, conventional learning referred to the Problem-Based Learning (PBL) model that had commonly been implemented by teachers. Although PBL is considered student-centered learning, critical thinking achievement remained lower than that of Inquiry-Based Learning, particularly STEAM-oriented Inquiry-Based Learning. This suggests that the difference lies not in student-centeredness, but rather in the depth of scientific processes facilitated by each model. Inquiry-based learning with systematic stages encourages students to engage in analysis, evaluation, and evidence-based conclusion drawing as core components of critical thinking skills (Pradana & Yasin, 2024).

The improvement in critical thinking skills was reflected in all indicators, including focus, reason, inference, situation, clarity, and overview. Students in the STEAM-oriented IBL class showed superior performance because they were actively involved in observing biodiversity phenomena, formulating hypotheses, conducting investigations, analyzing data, designing prototypes, and reflecting on their learning processes. These findings are supported by Arifin et al. (2025), who found that inquiry orientation activities improve students' abilities to identify scientific problems, as well as Furtak et al. (2021), who reported that inquiry learning based on

data analysis enhances students' abilities to draw scientific conclusions. Moreover, Syukri et al. (2022) demonstrated that STEAM-based learning strengthens students' analytical, evaluative, and scientific communication skills through interdisciplinary and collaborative activities. Similarly, Nursabrina et al. (2023) found that guided inquiry learning significantly improves students' abilities to construct evidence-based explanations. In line with these findings, Safitri et al. (2025) reported that inquiry-based electronic worksheets trained students' science process skills and supported analytical thinking through investigative and collaborative learning activities.

Cognitive Learning Outcomes

The improvement in students' cognitive learning outcomes was closely related to the implementation of each phase in the STEAM-oriented Inquiry-Based Learning model, which systematically developed cognitive abilities from lower-order to higher-order thinking skills. In the initial phases, students activated prior knowledge through worksheets, direct observations, and contextual problem situations, which supported C1 (remembering), C2 (understanding), and C3 (applying) skills. This process aligns with David Ausubel's learning theory, which emphasizes the importance of connecting new knowledge with existing cognitive structures, and is supported by Nurwahid et al. (2024), who found that inquiry orientation activities improve students' conceptual understanding.

In the following phases, students formulated hypotheses, conducted investigations, analyzed data, and evaluated evidence through collaborative discussions and STEAM-based activities. These activities developed C4 (analyzing) and C5 (evaluating) skills because students were required to interpret information, compare findings, and assess hypotheses based on evidence. Mantulangi et al. (2025) also reported that STEAM-based investigative activities significantly enhance students' analytical and evaluative abilities. Furthermore, in the conclusion and reflection phases, students generated integrated explanations, designed applicable solutions, and reflected on their learning processes, which contributed to C6 (creating) and metacognitive development. These findings are consistent with Vygotsky's theory emphasizing the role of reflection and social interaction in knowledge internalization, and are supported by Herung et al. (2025), who found that reflection activities improve metacognitive skills and conceptual understanding. Supporting these findings, Safitri et al. (2025) explained that inquiry-based learning activities not only improve science process skills but also strengthen students' conceptual understanding and cognitive achievement through active engagement in investigations and collaborative problem solving.

Differences in cognitive learning improvement were observed across the three classes. The conventional learning class showed the lowest improvement (20.43%), the Inquiry-Based Learning class demonstrated moderate improvement (62.79%), and the STEAM-oriented Inquiry-Based Learning class achieved the highest improvement (88.90%). These findings indicate that more systematic and in-depth inquiry processes lead to more optimal cognitive development. Therefore, the STEAM-oriented Inquiry-Based Learning model proved to be more effective in improving students' cognitive learning outcomes and promoting higher-order thinking skills comprehensively.

CONCLUSION

The results of this study indicate that the STEAM-oriented Inquiry-Based Learning (IBL) model significantly affects students' critical thinking skills and cognitive learning outcomes in biodiversity learning. Students taught using the STEAM-oriented IBL model showed the highest improvement compared to those taught through IBL and conventional learning, with critical thinking skills increasing by 85.37% and cognitive learning outcomes by 88.90%. The ANCOVA results confirmed significant effects on critical thinking skills ($p < 0.001$; $\eta^2 = 0.734$) and cognitive learning outcomes ($p < 0.001$; $\eta^2 = 0.742$), both categorized as large effect sizes. These findings suggest that integrating inquiry processes with STEAM elements creates more

meaningful learning experiences and supports higher-order thinking skills through activities such as problem identification, investigation, data analysis, and reflection.

However, the findings of this study are limited to Grade X students at SMA Laboratorium UM within a quasi-experimental design and a relatively short treatment duration. Therefore, future studies are recommended to examine the implementation of STEAM-oriented Inquiry-Based Learning in different biology topics, broader educational contexts, longer learning periods, and other 21st-century skills variables to obtain more comprehensive findings.

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