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Mapping High School Students' Critical Thinking in Biodiversity Learning through Problem-Based Learning and Structured Worksheets

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Abstract

This study aimed to explore and describe how the implementation of Problem-Based Learning (PBL), supported by structured student worksheets, facilitated high school students' critical thinking during biodiversity learning, particularly in identifying problems, analyzing information, evaluating evidence, formulating arguments, and drawing conclusions. The participants were 66 Grade X students from a senior high school in Flores, East Nusa Tenggara, Indonesia. Data were collected during eight classroom meetings and analyzed through indicator-based coding, thematic interpretation, item-level descriptive analysis, and cross-source triangulation. The findings showed that 14 of 20 critical-thinking indicators, or 70%, were consistently observed during the PBL process, especially indicators related to connecting ideas, considering perspectives, distinguishing facts from opinions, evaluating consequences, constructing logical arguments, reflecting on thinking processes, validating information, and proposing solutions. Students' questionnaire responses were positive, ranging from 83.3% to 90.9%, with an average positive response of 88.0%. However, six indicators still required stronger teacher scaffolding, particularly those related to formulating clear problems, collecting relevant information independently, asking relevant questions, evaluating arguments, providing deeper explanations, and developing creative solutions. This study contributes classroom-based evidence by clarifying the alignment among PBL stages, worksheet prompts, and critical-thinking indicators. The findings imply that should be supported by explicit guidance, evidence-based questioning, argumentation prompts, and reflective assessment.

Keywords: Biodiversity education, Critical thinking, Problem based learning, Structured worksheets, Mixed methods

1. Introduction

Critical thinking is a core competence in science education because students are expected to interpret information, evaluate evidence, construct arguments, and make reasoned decisions in complex real-life situations (Halpern & Dunn, 2021; Salamanca et al., 2020). In biology learning, critical thinking is closely associated with scientific reasoning, causal explanation, evidence evaluation, and the ability to connect concepts to environmental phenomena (Braun et al., 2016; Osborne & Pimentel, 2023). Therefore, biology instruction should not only emphasize concept acquisition but also provide learning experiences that train students to question information, examine assumptions, and justify conclusions using relevant evidence.

Biodiversity provides a meaningful context for developing critical thinking because it involves complex ecological relationships, species interactions, conservation dilemmas, human activities, and environmental change. Students are expected not only to understand the levels and components of biodiversity but also to analyze the causes and consequences of biodiversity decline, including habitat degradation, pollution, overexploitation, invasive species, and climate-related pressures (Wiegelmann & Zabel, 2021; Yli-Panula et al., 2018). However, biodiversity learning often remains theoretical when students are primarily asked to memorize definitions, identify species, or classify organisms. Such learning may support conceptual understanding, but it does not necessarily show whether students are able to identify problems, interpret information, evaluate evidence, formulate arguments, and propose evidence-based solutions. Therefore, mapping students' critical-thinking indicators is necessary to identify which indicators actually emerge during the learning process, which indicators remain underdeveloped, and how the stages of Problem-Based Learning and structured worksheet activities support their development. The mapping also provides an empirical basis for evaluating the quality of students' reasoning and improving the design of biodiversity learning activities and assessment.

Problem-Based Learning (PBL) offers a relevant approach for addressing this issue because it places students in contextual problem situations that require inquiry, collaboration, analysis, and reflection (Kek & Huijser, 2017; Silver et al., 2019). In PBL, students are encouraged to identify problems, collect information, compare explanations, formulate hypotheses, discuss alternative solutions, and evaluate the implications of their decisions. Previous studies have reported that PBL can promote critical thinking, problem-solving, and student engagement in science and biology learning (Anggraeni et al., 2023; Iwan et al., 2024; Sholihah & Lastariwati, 2020). Nevertheless, the success of PBL depends on the clarity of the problem scenario, the quality of teacher scaffolding, the availability of structured learning tools, and the readiness of students to work with open-ended problems.

Structured student worksheets are important in PBL because they can translate broad learning problems into sequenced thinking tasks. Well-designed worksheets may guide students from problem identification to evidence gathering, hypothesis formulation, decision-making, and reflection. In the context of critical-thinking development, worksheets should not merely ask students to fill in answers; they should help students organize reasoning, distinguish evidence from opinion, evaluate alternatives, and justify solutions. This alignment between PBL stages and critical-thinking indicators is essential because critical thinking does not automatically emerge from group discussion or problem presentation alone.

Although PBL has been widely studied, there is still a need for more classroom-based evidence that explains how specific indicators of critical thinking appear during PBL implementation in high school biodiversity learning. Many studies focus on learning outcomes or general perceptions, while fewer studies describe the alignment among PBL stages, worksheet questions, classroom activities, and critical-thinking indicators (Dadlı & Ural, 2024; Mardhatillah et al., 2020; Suwono et al., 2023). This gap is important because critical thinking is multidimensional; it includes problem formulation, information selection, argument evaluation, perspective taking, decision-making, and metacognitive reflection (Ennis, 2018).

The novelty of this study lies in its indicator-based mapping of critical-thinking development in biodiversity learning through Problem based learning (PBL) supported by structured worksheets in a local Indonesian high school context. Rather than making a causal claim that PBL statistically improves students' critical-thinking skills, this study identifies which critical-thinking indicators were consistently observed, which indicators remained weak, how worksheet questions supported students' reasoning processes, and what forms of teacher scaffolding were needed during implementation. Accordingly, this study was guided by three research questions: (1) which critical-thinking indicators emerged during PBL-based biodiversity learning? (2) how did structured worksheets support students' critical thinking processes? and (3) what difficulties were identified in developing students' critical thinking during PBL implementation?

2. Methods

This study used a descriptive mixed-methods design. The design was selected because the study integrated qualitative evidence from classroom observations, teacher interviews, teaching documents, structured worksheets, and student answer sheets with descriptive quantitative evidence from student response questionnaires. The qualitative component was used to interpret how critical-thinking indicators appeared during the learning process, whereas the descriptive quantitative component summarized students' perceptions of the problem based learning activities. This design was appropriate because the purpose of the study was to describe and interpret classroom-based learning phenomena rather than to test causal effects through inferential statistics

The study was conducted during the 2024-2025 academic year at a high school in Flores, East Nusa Tenggara, Indonesia. The participants were 66 Grade X students selected from two of six available classes. The class selection considered students' participation in biodiversity learning, the teacher's readiness to implement PBL, and the feasibility of observing the learning process across several meetings. Data collection was conducted during eight classroom meetings within one semester. Research permission was obtained from the school, students' identities were anonymized, and the data were reported only for academic purposes.

The learning topic focused on biodiversity, particularly the decline of species diversity in tropical forest ecosystems. This topic was selected because it allowed students to analyze ecological relationships, identify causal factors, evaluate evidence, and propose conservation-oriented solutions. The PBL activities were supported by structured student worksheets containing seven guiding questions. These questions were designed to guide students through problem orientation, problem analysis, conceptual clarification, evidence gathering, hypothesis formulation, solution design, and reflection.

Data sources and instruments are summarized in Table 1. The observation checklist consisted of 20 critical-thinking indicators adapted from Ennis' framework and aligned with the PBL stages, worksheet prompts, and biodiversity learning activities. The questionnaire used a five-point Likert scale to capture students' perceptions of the learning process. The teacher interview explored student engagement, barriers to critical thinking, and scaffolding strategies. Document analysis focused on teaching modules, worksheets, and selected student answer sheets.

Table 1.
Data sources, Analytical focus, and Credibility strategies

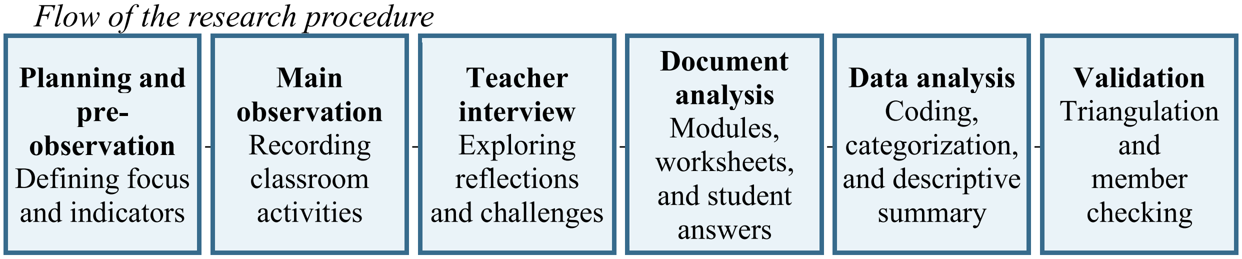
Data source	Main focus	Analytical procedure	Credibility strategy
Classroom observation	Student activities related to 20 critical-thinking indicators	Indicator based coding and categorization into developed or needs scaffolding	Cross checked with worksheet evidence and teacher reflection
Student response questionnaire	Students' perceptions of PBL-based biodiversity learning	Descriptive percentage summary of positive and less positive responses	Compared with observation patterns
Teacher interview	Teacher reflections on student engagement, difficulties, and facilitation	Thematic reduction and interpretation	Member checking with the teacher
Teaching documents and worksheets	Alignment between PBL stages, worksheet questions, and critical thinking processes	Document analysis and alignment mapping	Triangulated with classroom observation
Student answer sheets	Evidence of reasoning, problem analysis, and solution formulation	Qualitative interpretation of answer patterns	Used as supporting evidence for indicator coding

The data collection procedure consisted of four stages. The first stage was pre-observation, which aimed to identify the classroom context, the learning topic, and the critical-thinking indicators to be observed. The second stage was classroom observation, during which student activities were documented and matched with critical-thinking indicators. The third stage was teacher interview, conducted after the learning process to obtain reflections on learning difficulties and instructional support. The fourth stage was document collection, including teaching modules, student worksheets, and student answer sheets.

Data analysis followed two complementary procedures. First, qualitative data were reduced, coded, categorized, and interpreted based on the 20 critical thinking indicators. Each indicator was categorized as developed when consistent evidence appeared in at least three sources, such as classroom observation, worksheet answers, teacher reflection, and student response patterns. Indicators were categorized as needing scaffolding when students still required substantial teacher direction or when evidence of independent critical thinking was inconsistent. Second, questionnaire data were summarized using percentages and item-level descriptive statistics to describe students' perceptions. The percentage of developed critical-thinking indicators was calculated by dividing the number of developed indicators by the total number of observed indicators and multiplying the result by 100.

Instrument quality and trustworthiness were strengthened through construct alignment and triangulation. The observation indicators were linked to the critical-thinking framework, the PBL syntax, and the worksheet questions to ensure conceptual consistency. The questionnaire was used only as descriptive perception data, not as a standardized test of critical thinking. To reduce interpretive bias, coding decisions were compared across classroom observation notes, worksheet responses, teacher interview evidence, and document analysis. Member checking with the biology teacher was used to confirm whether the interpretation of classroom events was consistent with the learning process. Formal inter-rater reliability was not calculated, therefore, the findings should be read as classroom-based descriptive evidence rather than causal or psychometric evidence.

Figure 1.
Flow of the research procedure



3. Result and Discussion

The findings are presented in five parts: (1) alignment between PBL stages and critical-thinking processes, (2) development of students' critical thinking indicators, (3) students' responses to the PBL-based learning process, (4) difficulties encountered during PBL implementation, and (5) overall implications for biodiversity learning. The results integrate observation, questionnaire, interview, worksheet, and document evidence so that the interpretation does not rely on a single source of data.

3.1. Alignment between PBL stages, worksheet questions, and Critical thinking processes

The structured worksheets were designed to guide students through the PBL process. Each guiding question corresponded to a particular thinking process, beginning with problem identification and ending with reflection. This alignment is important because PBL requires students to move gradually from understanding the problem to evaluating possible solutions. Table 2 presents the alignment between PBL stages, worksheet questions, and the targeted critical-thinking processes.

Table 2.
Alignment between PBL stages, Worksheet questions, and targeted Critical thinking processes

No.	PBL stage	Worksheet question	Targeted critical thinking process
1	Problem orientation	What are the main issues related to the decline of species diversity in tropical forest ecosystems?	Problem identification and issue clarification
2	Problem analysis	Which factors contribute to these issues, and how do they interact within the ecosystem?	Cause-effect analysis and systems thinking
3	Conceptual clarification	Which concepts and principles should be understood to address the decline in species diversity?	Conceptual connection and knowledge organization
4	Evidence gathering	What data or evidence is available regarding species populations and environmental conditions relevant to this issue?	Information selection and evidence evaluation
5	Hypothesis formulation	Based on the collected information, what hypotheses can be proposed regarding the primary causes of biodiversity decline?	Hypothesis construction and reasoning
6	Solution design	What actions can be taken to mitigate negative impacts on species diversity, and why are these actions considered effective?	Decision-making, justification, and solution evaluation
7	Reflection	What lessons can be learned from analyzing this issue regarding the relationship between human activities and biodiversity, and how can this understanding be applied in the future?	Metacognitive reflection and transfer of learning

The alignment in **Table 2** indicates that the worksheets functioned as scaffolding tools rather than simple answer sheets. The questions required students to identify ecological problems, analyze causal relationships, select evidence, formulate hypotheses, justify conservation actions, and reflect on the broader implications of human activities for biodiversity. This structure supports the argument that critical thinking must be trained through deliberate and sequenced learning tasks rather than expected to emerge spontaneously from classroom discussion (Rivas et al., 2022; Sujatmika & Wibowo, 2020).

3.2 Development of students' critical-thinking indicators

Observation, worksheet, interview, and document evidence showed that 14 of 20 critical-thinking indicators, or 70%, were consistently observed during the PBL-based biodiversity learning process. The developed indicators were mostly related to analytical reasoning, perspective taking, evidence use, implication analysis, argument construction, and solution formulation. In contrast, six indicators still needed stronger scaffolding, particularly those related to problem formulation, independent information collection, relevant questioning, argument evaluation, deep explanation, and creative problem-solving.

Table 3.
Development of students' critical-thinking indicators during PBL-based biodiversity learning

No.	Critical thinking indicator	Category	Classroom based evidence and interpretation
1	Ability to formulate problems clearly	Needs scaffolding	Students still needed teacher guidance to transform the biodiversity phenomenon into a clear problem statement.
2	Skill in collecting relevant information	Needs scaffolding	Students tended to wait for direction before identifying relevant sources or evidence.
3	Proficiency in connecting different ideas	Developed	Students connected biodiversity decline with habitat change, human activity, and ecosystem stability.
4	Ability to provide deep explanations	Needs scaffolding	Some explanations remained descriptive and did not yet include sufficient evidence or causal reasoning.
5	Skill in asking relevant questions	Needs scaffolding	Students asked questions, but not all questions directly supported problem analysis or evidence evaluation.
6	Ability to evaluate arguments or opinions	Needs scaffolding	Students required more examples to distinguish strong arguments from unsupported opinions.

No.	Critical thinking indicator	Category	Classroom based evidence and interpretation
7	Proficiency in considering different perspectives	Developed	Group discussion encouraged students to compare different viewpoints before proposing solutions.
8	Ability to filter information accurately	Developed	Students selected information related to species decline, environmental conditions, and human impacts.
9	Skill in distinguishing facts from opinions	Developed	Students began to separate observation-based information from personal assumptions during discussion.
10	Ability to make generalizations based on evidence	Developed	Students drew broader conclusions about biodiversity decline from the evidence discussed.
11	Proficiency in solving problems creatively	Needs scaffolding	Proposed solutions were relevant but still tended to follow common examples and required more originality.
12	Ability to identify assumptions underlying an opinion	Developed	Students identified assumptions related to human activity, habitat disturbance, and conservation choices.
13	Skill in evaluating consequences of decisions	Developed	Students considered possible impacts of conservation or mitigation actions on ecosystems.
14	Ability to construct logical and coherent arguments	Developed	Students used claims and reasons to justify solutions, although the depth of evidence varied.
15	Proficiency in reflecting on one's own thinking process	Developed	Reflection questions encouraged students to revisit their reasoning and learning process.
16	Ability to test the validity of received information	Developed	Students discussed whether information was relevant and reasonable for explaining biodiversity decline.
17	Skill in comparing and contrasting information	Developed	Students compared multiple causes of biodiversity loss and their ecological consequences.
18	Ability to consider implications of an action	Developed	Students considered future implications of human activity and conservation action.

No.	Critical thinking indicator	Category	Classroom based evidence and interpretation
19	Skill in making decisions based on critical analysis	Developed	Students selected mitigation actions after considering causes and consequences.
20	Ability to offer solutions based on problem analysis	Developed	Students proposed solutions that were connected to the identified biodiversity problems.

The pattern in **Table 3** shows that, within the observed classroom context, PBL supported analytical and reflective indicators more clearly than independent inquiry indicators. Students were able to connect ideas, compare information, consider implications, and propose solutions because the learning scenario provided a concrete biodiversity problem. This finding is consistent with the view that PBL encourages students to work with authentic problems, evaluate perspectives, and construct explanations through discussion (Kek & Huijser, 2017; Silver et al., 2019). It also supports previous findings that PBL can promote critical thinking when students are required to interpret information and justify decisions (Anggraeni et al., 2023; Yu & Zin, 2023).

At the same time, the indicators that remained weak reveal an important pedagogical issue. Formulating problems, asking relevant questions, evaluating arguments, and developing creative solutions do not automatically develop when students are placed in groups or given open-ended problems. These skills require explicit teacher modeling, examples of high quality reasoning, guided questioning, and feedback. This finding aligns with Gunawardena & Wilson, (2021), who emphasized that scaffolding is a continuous process that helps students move from guided reasoning toward independent critical thinking.

3.3. Students' responses to the PBL based learning process

The student response questionnaire showed that 88% of students perceived the PBL based learning process as meaningful for supporting critical-thinking activities, while 12% gave less positive responses. This finding indicates that most students experienced the learning activities as supportive because they were encouraged to discuss real problems, connect biodiversity concepts to environmental issues, and present solutions. However, the response data should be interpreted as descriptive evidence of student perceptions rather than as statistical proof of effectiveness.

Figure 2.
Students' responses to the PBL-based learning process

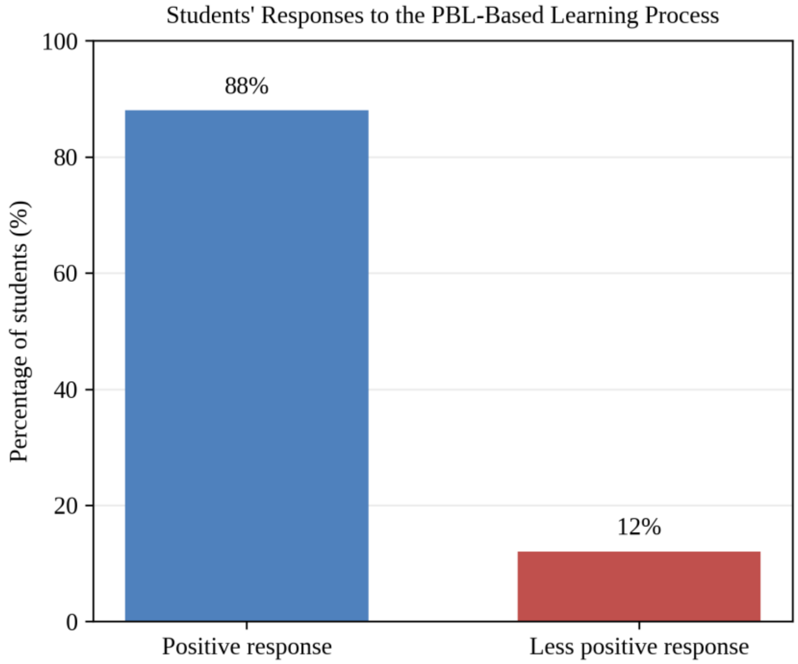


Table 4.
Descriptive summary of student responses

Response category	Percentage	Interpretation
Positive response	88%	Most students perceived PBL-based biodiversity learning as meaningful for supporting critical thinking.
Less positive response	12%	Some students still needed adaptation, clearer guidance, or more structured support in open-ended learning tasks.

A more detailed item-level analysis was conducted to clarify the overall percentage of positive student responses. The item-level data showed that positive responses ranged from 83.3% to 90.9%, with an average positive response of 88.0%. The highest positive response was found in the item related to considering different perspectives during group discussion, whereas the lowest positive response was related to teacher guidance in formulating clearer problem statements. This pattern indicates that PBL strongly supported collaborative reasoning and perspective taking, but students still required scaffolding in problem formulation and independent inquiry.

Table 5.
Item-level recapitulation of student questionnaire responses (n = 66)

Code	Questionnaire item	SA	A	N	D	SD	Mean	Positive (%)
Q1	PBL helped me understand biodiversity problems more clearly.	32	27	5	2	0	4.35	89.4
Q2	The structured worksheet guided me to identify the main problem.	29	30	5	2	0	4.30	89.4
Q3	The activities helped me connect biodiversity concepts with environmental phenomena.	30	28	6	2	0	4.30	87.9
Q4	Group discussion helped me consider different perspectives.	31	29	4	2	0	4.35	90.9
Q5	The worksheet trained me to select and evaluate relevant information.	28	29	7	2	0	4.26	86.4
Q6	PBL activities helped me distinguish facts from opinions.	27	31	6	2	0	4.26	87.9
Q7	The learning process trained me to construct logical arguments.	25	32	7	2	0	4.21	86.4
Q8	The activities encouraged me to propose evidence-based solutions.	30	28	6	2	0	4.30	87.9
Q9	Reflection questions helped me evaluate my own thinking process.	28	30	6	2	0	4.27	87.9
Q10	Teacher guidance helped me formulate clearer problem statements.	24	31	8	3	0	4.15	83.3
Q11	The worksheet helped me design conservation-oriented actions.	30	29	5	2	0	4.32	89.4
Q12	Overall, PBL-based biodiversity learning was meaningful for developing critical thinking.	33	26	5	2	0	4.36	89.4

Note. SA = strongly agree; A = agree; N = neutral; D = disagree; SD = strongly disagree. The dimension analysis indicated that Q1 and Q3 represented understanding of biodiversity problems; Q2, Q5, Q9, and Q11 represented worksheet scaffolding; Q4, Q7, and Q8 represented collaborative reasoning; Q10 represented teacher scaffolding; and Q12 represented the overall learning experience.

The positive responses may be explained by the active nature of PBL. Students were not only asked to listen to explanations but also to analyze biodiversity problems, discuss possible causes, evaluate information, and present solutions. These activities are aligned with critical-thinking habits because students must justify their ideas and respond to the perspectives of others (Plummer et al., 2022; Sellars et al., 2018). In biodiversity learning, such activities are important because ecological problems usually involve multiple causes and require careful consideration of evidence and implications.

The 12% less positive response is also meaningful. Some students may have found PBL challenging because it requires independence, collaboration, and the ability to work with open-ended problems. Students who are accustomed to direct explanation and factual questions may need more time to adapt to inquiry-oriented learning. Therefore, teachers should provide gradual orientation, clear group roles, guiding questions, and feedback so that students with different levels of readiness can participate more equally.

3.4. Evidence from student worksheets, teacher interviews, and triangulation

Analysis of selected worksheet answers showed three levels of response quality. Strong responses included causal explanation, relevant ecological evidence, and solution justification. Moderate responses identified relevant causes but remained general and lacked detailed evidence. Weak responses were broad, descriptive, and required teacher prompts. These patterns indicate that structured worksheets helped organize students' reasoning, but the quality of critical thinking depended on the extent to which students could connect claims, evidence, and ecological concepts.

Table 6.
Examples of student worksheet answers and critical-thinking interpretation

Student code	Quality level	Example answer from worksheet	Analytical interpretation
S-18	Strong	The main issue is the decline of species diversity caused by habitat destruction, illegal logging, and land conversion. These activities reduce food sources, nesting areas, and ecological balance. If the habitat continues to be disturbed, some species may migrate or disappear from the ecosystem.	Connects causes and consequences; uses ecological reasoning; indicates developed indicators related to connecting ideas, evaluating consequences, and offering solutions.

Student code	Quality level	Example answer from worksheet	Analytical interpretation
S-27	Moderate	Species diversity decreases because many trees are cut and animals lose their homes. Pollution and hunting also affect the forest. The solution is to protect the forest and plant more trees.	Relevant but still general; needs stronger evidence and deeper explanation; indicates partial development of problem analysis and solution formulation.
S-44	Needs scaffolding	Biodiversity decreases because humans damage nature. We should not damage the forest so animals can live.	Answer is too broad; causal mechanisms and evidence are weak; needs teacher prompts for problem formulation, evidence selection, and deeper explanation.

The teacher interview supported the worksheet analysis. The teacher reported that students became more active when biodiversity problems were connected to real environmental issues, but several students still needed guidance in formulating scientific problems, selecting relevant information, and connecting claims with evidence. This qualitative evidence explains why some indicators were categorized as developed while others were categorized as needing scaffolding.

Table 7.
Teacher interview evidence used to interpret Critical thinking development

Code	Theme	Teacher quote	Interpretation
BT-Q1	Student engagement	Students became more active when the problem was connected to real environmental issues. They were more willing to discuss because the topic was close to what they often see around them.	PBL increased student engagement through contextual biodiversity problems.
BT-Q2	Problem formulation	At the beginning, many students could mention the problem, but they still had difficulty formulating it into a clear scientific question.	Problem formulation remained a weak critical-thinking indicator.

Code	Theme	Teacher quote	Interpretation
BT-Q3	Information selection	Some students still waited for guidance before deciding which information was relevant to the problem.	Independent information collection required stronger scaffolding.
BT-Q4	Argument construction	Their arguments improved during discussion, but several groups still needed examples of how to connect claims with evidence.	Claim-evidence-reasoning prompts were needed.
BT-Q5	Worksheet function	The worksheet helped students follow the steps of thinking, from identifying the problem to proposing solutions.	Structured worksheets functioned as scaffolding tools.
BT-Q6	Teacher scaffolding	PBL works better when the teacher gives guiding questions and feedback, especially for students who are not used to open-ended tasks.	Teacher scaffolding is necessary for uneven student readiness.

Triangulation was conducted by comparing evidence from classroom observation, student worksheets, student questionnaire responses, and teacher interviews. An indicator was interpreted as developed when at least three sources provided consistent evidence. When the evidence was inconsistent or when students still required substantial teacher guidance, the indicator was categorized as needing scaffolding. This procedure strengthened the credibility of the interpretation and reduced dependence on a single data source.

Table 8.
Triangulation matrix of Critical thinking Evidence

Critical-thinking focus	Observation and worksheet evidence	Teacher interview evidence	Questionnaire evidence	Conclusion
Connecting different ideas	Students linked biodiversity decline with habitat disturbance, pollution, and human activities; worksheet answers connected causes and consequences of species decline.	Teacher noted that students became more able to relate concepts after discussion.	Q3 positive response = 87.9%	Developed

Critical-thinking focus	**Observation and worksheet evidence**	**Teacher interview evidence**	**Questionnaire evidence**	**Conclusion**
Considering different perspectives	Group discussion showed students compared ecological, human, and conservation perspectives; students proposed solutions involving community action, forest protection, and regulation.	Teacher observed that students listened to other group members before presenting conclusions.	Q4 positive response = 90.9%	Developed
Distinguishing facts from opinions	Students began separating observed evidence from assumptions; some answers used evidence such as habitat loss and pollution, while others remained opinion-based.	Teacher stated that evidence prompts were needed to avoid unsupported claims.	Q6 positive response = 87.9%	Developed, but needs reinforcement
Formulating problems clearly	Students needed teacher prompts to convert the phenomenon into a clear problem statement; several worksheet answers were broad.	Teacher confirmed that problem formulation was difficult at the beginning of PBL.	Q10 positive response = 83.3%	Needs scaffolding
Collecting relevant information	Students tended to wait for direction before choosing relevant evidence; worksheet responses varied in evidence quality.	Teacher stated that students needed guidance to identify relevant information.	Q5 positive response = 86.4%	Needs scaffolding
Constructing logical arguments	Students used claims and reasons during group presentations; strong answers included cause-effect explanation while weak answers were descriptive.	Teacher noted that claim-evidence-reasoning examples helped students improve.	Q7 positive response = 86.4%	Partially developed

Critical-thinking focus	Observation and worksheet evidence	Teacher interview evidence	Questionnaire evidence	Conclusion
Proposing evidence-based solutions	Students proposed conservation actions after discussing causes and consequences, including reforestation, habitat protection, and reducing hunting.	Teacher observed that solutions were relevant but often conventional.	Q8 positive response = 87.9%	Developed, but creative design needs support

3.5. Difficulties in developing critical thinking during PBL implementation

Although PBL and structured worksheets supported several aspects of critical thinking, the triangulation of observation, teacher interview, and document analysis identified several difficulties. These difficulties were related to conceptual readiness, information selection, argument construction, independent inquiry, creative solution design, and transfer of learning. Table 9 summarizes the themes and instructional refinements needed for future implementation.

Table 9.
Difficulties and instructional refinements for strengthening Critical thinking

No.	Theme	Observed difficulty	Instructional refinement
1	Conceptual readiness	Some students had limited prior understanding of ecological relationships and biodiversity concepts.	Provide short conceptual reinforcement before students analyze complex problems.
2	Information selection	Students still needed help identifying which information was relevant to the problem.	Use source-evaluation checklists and guiding questions.
3	Argument construction	Some arguments were descriptive and not fully supported by evidence.	Introduce claim-evidence-reasoning prompts and examples of strong arguments.
4	Independent inquiry	Students tended to wait for teacher direction during early problem analysis.	Assign clear inquiry roles and gradually reduce teacher support.
5	Creative problem-solving	Proposed solutions were relevant but often conventional.	Use brainstorming, comparison of alternatives, and justification rubrics.

No.	Theme	Observed difficulty	Instructional refinement
6	Transfer of learning	Students needed support connecting classroom problems to local environmental contexts.	Use local biodiversity cases and reflection tasks linked to students' surroundings.

The difficulties in **Table 9** show that critical thinking develops gradually and requires continuous instructional support. Students with limited conceptual readiness found it more difficult to evaluate data, formulate hypotheses, or construct explanations. This supports the argument that prior knowledge influences students' ability to solve complex problems and engage in higher-order reasoning (LaForce et al., 2017; Vosniadou, 2019). Therefore, PBL should begin with enough conceptual preparation so that students can analyze problems meaningfully rather than simply guess possible answers.

Argument construction was another major challenge. Although students could discuss biodiversity problems and propose solutions, several explanations remained descriptive and were not fully supported by evidence. Strong argumentation requires students to connect claims, evidence, reasoning, and implications, which is demanding for many learners (Iordanou & Rapanta, 2021; Plummer et al., 2022). Therefore, future PBL implementation should include argumentation prompts, examples of high-quality explanations, peer review, and rubrics that make the expected reasoning standards explicit.

The findings also indicate the importance of contextualizing biodiversity problems. Students can understand the relevance of biodiversity more clearly when classroom examples are connected to environmental problems in their surroundings. Contextual learning helps students transfer biological concepts to real-life situations and strengthens the practical value of critical thinking (Tari & Rosana, 2019). Thus, PBL in biodiversity learning should include local cases, such as habitat disturbance, species decline, waste, land-use change, or conservation challenges that students can observe in their community.

3.6. Overall discussion, Contribution, and Implications

Overall, this study indicates that PBL supported by structured worksheets can create a meaningful learning environment in which several critical-thinking indicators become observable during biodiversity learning. The strongest evidence was found in indicators related to connecting ideas, evaluating implications, constructing arguments, validating information, making analytical decisions, and proposing solutions. These indicators emerged because students were exposed to contextual biodiversity problems and were required to discuss, analyze, and justify their responses. This finding strengthens previous research showing that PBL encourages active engagement, collaboration, and reflective inquiry in science education (Anggraeni et al., 2023; Mutiara et al., 2024; Sholihah & Lastariwati, 2020).

The contribution of this study is not limited to showing that PBL is beneficial. More specifically, the study provides an indicator-based map of which critical-thinking skills were developed and which skills still needed instructional scaffolding. This distinction is important for teachers and curriculum designers because critical thinking should be treated as a set of specific teachable indicators rather than a broad and abstract learning outcome. If critical thinking is intended as a learning objective, then learning activities, worksheet questions, classroom facilitation, and assessment rubrics must be constructively aligned.

The practical implication is that biology teachers can use PBL to move biodiversity learning from memorization toward reasoning, problem analysis, and solution-oriented learning. However, teachers should not rely only on the existence of problems or group work. They need to provide structured worksheets, guiding questions, argumentation prompts, source-evaluation activities, and reflective tasks. For researchers, the findings provide a foundation for more rigorous future studies using pretest-posttest designs, validated critical-thinking tests, comparison groups, or longitudinal observation to examine the development of critical thinking more robustly.

This study has several limitations that define the scope and interpretation of its findings. First, the study was bounded within one school and one biodiversity classroom context. Therefore, the findings should be interpreted as context-specific classroom evidence rather than statistically generalized to all high school students. Qualitative case-study research is intended to provide an in-depth understanding of a phenomenon within its real-life context, while the relevance of its findings to other settings depends on the similarity of participants, instructional conditions, and school environments (Harrison et al., 2017). Clear reporting of the research context, participants, data sources, analytic procedures, and boundaries of interpretation is consequently essential for maintaining methodological integrity in qualitative research (Levitt et al., 2018).

Second, the questionnaire data were analyzed descriptively and were used to complement classroom observations, learning documents, student worksheets, and teacher reflection. Therefore, the questionnaire results should not be interpreted as evidence of a causal effect of PBL on students' critical thinking. Establishing causal effectiveness requires a design that defines the intervention, comparison conditions, outcomes, assumptions, and possible alternative explanations more explicitly (Hanckel et al., 2021). Because this study did not employ a pretest–posttest control-group or quasi-experimental design, it cannot claim statistically significant improvement attributable solely to PBL.

Third, although the use of observations, documents, worksheet evidence, and teacher reflection provided multiple sources of classroom data, this study did not include in-depth student interviews or stimulated-recall sessions. Future studies should incorporate these techniques to explore why students selected particular evidence, how they evaluated alternative explanations, and how they formulated their conclusions. The use of a clearly defined coding framework or critical-thinking rubric would also strengthen the systematic identification of interpretation, analysis, evaluation, inference, explanation, and evidence-based decision-making in students' responses. Transparent documentation of data familiarization, coding, theme or category development, review, and interpretation is important for demonstrating the rigor of qualitative analysis (Kiger & Varpio, 2020).

Fourth, the coding of critical-thinking indicators was not examined through formal intercoder agreement. Future research should involve at least two coders who independently analyze a proportion of the data, compare coding decisions, discuss disagreements, and refine the definitions and boundaries of each indicator. Intercoder assessment can improve the systematicity, transparency, communicability, and trustworthiness of a coding framework when it is consistent with the selected qualitative approach (O'Connor & Joffe, 2020). These limitations do not diminish the value of the study but clarify that its contribution lies in mapping observable critical-thinking indicators and explaining how these indicators appeared within a particular PBL-based biodiversity classroom.

4. Conclusion

This study concludes that Problem Based Learning supported by structured student worksheets can support the emergence of observable critical-thinking indicators in high school biodiversity learning Observation data showed that 14 of 20 critical-thinking indicators, or 70%, were developed during the learning process. The developed indicators were mainly related to connecting ideas, considering different perspectives, distinguishing facts from opinions, identifying assumptions, evaluating consequences, constructing logical arguments, reflecting on thinking processes, validating information, comparing information, considering implications, making analytical decisions, and proposing solutions. Student response data also showed that item-level positive responses ranged from 83.3% to 90.9%, with an average positive response of 88.0%

Despite these positive findings, six indicators were not yet consistently developed: formulating problems clearly, collecting relevant information independently, asking relevant questions, evaluating arguments, providing deep explanations, and solving problems creatively. This indicates that PBL should be accompanied by explicit teacher scaffolding, strong worksheet design, and clear assessment rubrics. Teachers are advised to provide modeling of analytical questions, evidence-based argumentation, source evaluation, reflection, and creative solution design. Future research should use stronger designs, such as quasi-experimental or longitudinal studies, validated critical-thinking instruments, and rubric-based analysis of students' written reasoning, to provide more robust evidence of the impact of PBL on critical-thinking development.

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References

Anggraeni, D. M., Prahani, B. K., Suprapto, N., Shofiyah, N., & Jatmiko, B. (2023). Systematic review of problem based learning research in fostering critical thinking skills. *Thinking Skills and Creativity*, *49*, 101334. https://doi.org/10.1016/j.tsc.2023.101334

Braun, V., Clarke, V., & Weate, P. (2016). *Using thematic analysis in sport and exercise research. In Routledge handbook of qualitative research in sport and exercise*. Routledge.

Dadlı, G., & Ural, E. (2024). The Effect Of Problem-Based Learning Activities On Secondary School Students' Awareness Of Biodiversity. *Scientific Educational Studies*, *8*(2), 60–90. https://doi.org/10.31798/ses.1489883

Ennis, R. H. (2018). Critical Thinking Across the Curriculum: A Vision. *Topoi*, *37*(1), 165–184. https://doi.org/10.1007/s11245-016-9401-4

Gunawardena, M., & Wilson, K. (2021). Scaffolding students' critical thinking: A process not an end game. *Thinking Skills and Creativity*, *41*, 100848. https://doi.org/10.1016/j.tsc.2021.100848

Halpern, D. F., & Dunn, D. S. (2021). Critical Thinking: A Model of Intelligence for Solving Real-World Problems. *Journal of Intelligence*, *9*(2), 22. https://doi.org/10.3390/jintelligence9020022

Hanckel, B., Petticrew, M., Thomas, J., & Green, J. (2021). The use of Qualitative Comparative Analysis (QCA) to address causality in complex systems: A systematic review of research on public health interventions. *BMC Public Health*, *21*(1), 877. https://doi.org/10.1186/s12889-021-10926-2

Harrison, H., Birks, M., Franklin, R., & Mills, J. (2017). Case Study Research: Foundations and Methodological Orientations. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *Vol 18*, No 1 (2017). https://doi.org/10.17169/FQS-18.1.2655

Iordanou, K., & Rapanta, C. (2021). "Argue With Me": A Method for Developing Argument Skills. *Frontiers in Psychology*, *12*, 631203. https://doi.org/10.3389/fpsyg.2021.631203

Iwan, Sumitro, S. B., Ibrohim, & Rohman, F. (2024). The Effectiveness of the Problem-Based Learning Model to Enhance Students' Critical Thinking Skills on Conservation Biology Courses. *Jurnal Penelitian Pendidikan IPA*, *10*(8), 4641–4649. https://doi.org/10.29303/jppipa.v10i8.6959

Kek, M. Y. C. A., & Huijser, H. (2017). *Problem-based Learning into the Future*. Springer Singapore. https://doi.org/10.1007/978-981-10-2454-2

Kiger, M. E., & Varpio, L. (2020). Thematic analysis of qualitative data: AMEE Guide No. 131. *Medical Teacher*, *42*(8), 846–854. https://doi.org/10.1080/0142159X.2020.1755030

LaForce, M., Noble, E., & Blackwell, C. (2017). Problem-Based Learning (PBL) and Student Interest in STEM Careers: The Roles of Motivation and Ability Beliefs. *Education Sciences*, *7*(4), 92. https://doi.org/10.3390/educsci7040092

Levitt, H. M., Bamberg, M., Creswell, J. W., Frost, D. M., Josselson, R., & Suárez-Orozco, C. (2018). Journal article reporting standards for qualitative primary, qualitative meta-analytic, and mixed methods research in psychology: The APA Publications and Communications Board task force report. *American Psychologist*, *73*(1), 26–46. https://doi.org/10.1037/amp0000151

Mardhatillah, A., Zaini, M., & Putra, A. P. (2020). Development of Worksheets for Biology High School Student-Based On Critical Thinking Skills on the Concept of Biodiversity. *BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan*, *2*(1), 31. https://doi.org/10.20527/bino.v2i1.7903

Mutiara, E., Suyanto, S., B, N. K. L., Laksita, G. D., & Zamzami, Z. (2024). Improving Critical Thinking Skills using Problem Based Learning: Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *10*(12), 988–995. https://doi.org/10.29303/jppipa.v10i12.7872

O'Connor, C., & Joffe, H. (2020). Intercoder Reliability in Qualitative Research: Debates and Practical Guidelines. *International Journal of Qualitative Methods*, *19*, 1609406919899220. https://doi.org/10.1177/1609406919899220

Osborne, J., & Pimentel, D. (2023). Science education in an age of misinformation. *Science Education*, *107*(3), 553–571. https://doi.org/10.1002/sce.21790

Plummer, K. J., Kebritchi, M., Leary, H. M., & Halverson, D. M. (2022). Enhancing Critical Thinking Skills through Decision-Based Learning. *Innovative Higher Education*, *47*(4), 711–734. https://doi.org/10.1007/s10755-022-09595-9

Rivas, S. F., Saiz, C., & Ossa, C. (2022). Metacognitive Strategies and Development of Critical Thinking in Higher Education. *Frontiers in Psychology*, *13*, 913219. https://doi.org/10.3389/fpsyg.2022.913219

Salamanca, J. C. G., Agudelo, O. L., & Salinas, J. (2020). Key Competences, Education for Sustainable Development and Strategies for the Development of 21st Century Skills. A Systematic Literature Review. *Sustainability*, *12*(24), 10366. https://doi.org/10.3390/su122410366

Sellars, M., Fakirmohammad, R., Bui, L., Fishetti, J., Niyozov, S., Reynolds, R., Thapliyal, N., Liu-Smith, Y.-L., & Ali, N. (2018). Conversations on Critical Thinking: Can Critical Thinking Find Its Way Forward as the Skill Set and Mindset of the Century? *Education Sciences*, *8*(4), 205. https://doi.org/10.3390/educsci8040205

Sholihah, T. M., & Lastariwati, B. (2020). Problem based learning to increase competence of critical thinking and problem solving. *Journal of Education and Learning (EduLearn)*, *14*(1), 148–154. https://doi.org/10.11591/edulearn.v14i1.13772

Silver, C. E. H., Bridges, S. M., & McKeown, J. M. (2019). Facilitating Problem-Based Learning. In *The Wiley Handbook of Problem-Based Learning* (1st ed., pp. 297–319). Wiley. https://doi.org/10.1002/9781119173243.ch13

Sujatmika, S., & Wibowo, W. S. (2020). Developing d-Worksheets by applying 7 steps of problem-based-learning to enrich students' critical thinking skills. *Journal of Physics: Conference Series*, *1567*(4), 042041. https://doi.org/10.1088/1742-6596/1567/4/042041

Suwono, H., Permana, T., Saefi, M., & Fachrunnisa, R. (2023). The problem-based learning (PBL) of biology for promoting health literacy in secondary school students. *Journal of Biological Education*, *57*(1), 230–244. https://doi.org/10.1080/00219266.2021.1884586

Tari, D. K., & Rosana, D. (2019). Contextual Teaching and Learning to Develop Critical Thinking and Practical Skills. *Journal of Physics: Conference Series*, *1233*(1), 012102. https://doi.org/10.1088/1742-6596/1233/1/012102

Vosniadou, S. (2019). The Development of Students' Understanding of Science. *Frontiers in Education*, *4*, 32. https://doi.org/10.3389/feduc.2019.00032

Wiegelmann, J., & Zabel, J. (2021). Biodiversity researchers as a model for school students: An innovative approach to foster meaningful understanding? *Environmental Education Research*, *27*(8), 1245–1262. https://doi.org/10.1080/13504622.2021.1905780

Yli-Panula, E., Jeronen, E., Lemmetty, P., & Pauna, A. (2018). Teaching Methods in Biology Promoting Biodiversity Education. *Sustainability*, *10*(10), 3812. https://doi.org/10.3390/su10103812

Yu, L., & Zin, Z. M. (2023). The critical thinking-oriented adaptations of problem-based learning models: A systematic review. *Frontiers in Education*, *8*, 1139987. https://doi.org/10.3389/feduc.2023.1139987