



The Role of Problem-Based Learning Model in Optimizing Senior High School Students' Critical Thinking Skills in Biodiversity Material: A Literature Review

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Abstract: Through PBL, students do not only memorize facts, but are invited to analyze real problems related to biodiversity, such as species extinction or ecosystem damage. This approach encourages students to find solutions, gather information from various sources, and develop logical arguments, which are the core of critical thinking. Thus, PBL effectively transforms passive learning into active learning, equipping students with essential skills to understand and contribute to global environmental issues. This research aims to analyze and explain the concept and characteristics of the Problem-Based Learning (PBL) Model; the relationship between PBL and critical thinking skills; identify the benefits and challenges of implementing PBL; and explain the implementation of PBL in biodiversity material. The objectives are to identify what is known, find research gaps, and provide a basis for further research. The results of this study are Problem-Based Learning (PBL) is an educational model that makes authentic problems the main foundation in the student learning process; PBL is student-centered, utilizing real problems to trigger independent investigation and group collaboration. This model aims to develop problem-solving and self-reflection skills. General stages of PBL include: Problem orientation: Introducing the problem to students; Student organization: Forming study groups; Guiding inquiry: Facilitating the search for solutions; Development and presentation of results: Presenting findings. • Process analysis and evaluation: Reflecting on learning; PBL is highly effective in improving students' critical thinking skills.

Keywords: Biodiversity materials; Critical thinking skills; Optimizing; Problem-based learning; Senior high school students

Introduction

In this fast-paced, information-rich modern era, critical thinking skills have become a necessity, no longer merely an added value. The 21st-century curriculum explicitly emphasizes the importance of this skill as a foundation for individual success in facing life's complexities and global challenges (Herlinawati et al., 2024; Almazroa & Alotaibi, 2023). Beyond simply memorizing facts, critical thinking enables one to

analyze information in-depth, carefully evaluate arguments, identify biases, and formulate innovative solutions. Without this ability, individuals will struggle to filter credible information from misinformation, make informed decisions, or contribute significantly to a constantly changing society. Therefore, developing critical thinking skills at every level of education, especially high school students (Amani & Mkimibili, 2025; Widyapuraya et al., 2023), is a top priority to prepare a generation that is adaptive, innovative, and

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competitive in the future. Although the importance of critical thinking is widely recognized, science learning, particularly biology, often faces significant challenges. Biology material, rich in concepts, terms, and processes, is often presented in a rote format (Assen & Otting, 2022; Miserez et al., 2023).

Students are often simply required to memorize definitions, identify parts, or memorize cycles without truly understanding the essence and interrelationships between concepts (Stanton et al., 2015). This approach under-stimulates reasoning and higher-order thinking skills, rendering learning dry and meaningless, and failing to facilitate the development of essential skills such as analysis, synthesis, evaluation, and complex problem-solving. This is ironic, considering the very nature of science, which should encourage curiosity, exploration, and logical thinking (Maqsood et al., 2025; Hogan & O'Flaherty, 2022). Among the various science subjects, biodiversity is a highly relevant topic, both academically and practically in everyday life (Suwistika et al., 2024; Septiany et al., 2024). However, the complexity of this material often demands more than mere memorization. Biodiversity encompasses a broad spectrum, from the genetic level to the species level to the ecosystem level, along with the dynamics of interactions within them (Raslan, 2023; Aizikovitsh-Udi & Cheng, 2015).

Understanding why a species is endangered, how the food chain works, or the impact of climate change on ecosystems requires a deep understanding of the principles of ecology, evolution, and conservation (Weiskopf et al., 2020; Niesenbaum, 2019). If students simply memorize the terms, they may not be able to analyze cause-and-effect relationships, predict the consequences of human actions, or formulate solutions to real-world environmental issues. Therefore, a learning approach that facilitates reasoning and problem-solving is crucial for students to appreciate, understand, and contribute to preserving the Earth's biodiversity. Given the challenges in science learning, which tends to rely on rote learning and lacks reasoning stimulation, as well as the complexity of material such as biodiversity that demands in-depth understanding, innovation in learning models is a necessity. Conventional teacher-centered approaches that emphasize memorization are no longer relevant to preparing students for the realities of the 21st century (Bhardwaj et al., 2025; Kim et al., 2019). To address these challenges and effectively develop students' critical thinking skills, we need to shift to more dynamic and student-centered strategies (Martin-Alguacil et al., 2024; Kerimbayev et al., 2023).

Innovative learning models must be able to create an active learning environment, stimulate curiosity, encourage independent exploration, and guide students

in analyzing problems, evaluating information, and formulating solutions (Salmon & Barrera, 2021). Only then can biology learning, particularly biodiversity, become a powerful tool for shaping the next generation who are not only cognitively intelligent but also possess the critical thinking skills necessary to face various future challenges. In this context, the Problem-Based Learning (PBL) Model presents itself as a prospective solution. Based on the above background, this research aims to analyze and explain the concept and characteristics of the Problem-Based Learning (PBL) Model; the relationship between PBL and critical thinking skills; identify the benefits and challenges of implementing PBL; and explain the implementation of PBL in biodiversity material.

Method

This research uses a review method, is an essential research method for comprehensively understanding a topic by synthesizing, analyzing, and evaluating existing research. Its purpose is to identify what is already known, identify research gaps, and provide a foundation for further research.

*Here are the Steps in Conducting a Literature Review:
Formulating a Clear Research Question*

This is the foundation of any literature review. The question must be specific, relevant, and answerable based on the existing literature.

Determining Inclusion and Exclusion Criteria

Once the research question is formulated, establish clear criteria for which studies will be included (inclusion) and excluded (exclusion). This helps limit the scope and ensure relevance: Inclusion Criteria: Publication type (peer-reviewed journal), publication year range, language, research design, study population, and topic focus; Exclusion Criteria: Unpublished conference papers, theses/dissertations, opinion articles, or studies that do not meet the inclusion criteria.

Conduct a Systematic Literature Search

This phase involves data collection, which must be conducted systematically and documented to ensure replication of the results: Select Databases: Identify relevant scientific databases (e.g., Scopus, Web of Science, PubMed, Google Scholar, ScienceDirect, ERIC, ProQuest); Use Keywords: Create broad and specific keyword combinations, including synonyms and Boolean operators (AND, OR, NOT) for optimal results; Document the Process: Record all databases used, the search date, the search string (full keywords), and the number of results found. This is important for transparency.

Article Screening and Selection

Once the search yields a large number of articles, conduct a two-stage screening: **Title and Abstract Screening:** Read the titles and abstracts of all articles found to identify potentially relevant ones. Eliminate those that clearly do not meet the criteria; **Full Text Reading:** For articles that pass the initial screening, download and read the full text. Ensure that the article fully meets all your inclusion criteria. Note the reasons why certain articles were excluded; **Tip:** Ideally, this process should be conducted by at least two people independently to reduce bias.

Data Extraction from Selected Articles

From each selected article, extract key information relevant to your research question. Create a structured data extraction sheet: **Extracted Data:** Bibliographic information (author, year, title), research design, study objectives, population/sample, variables studied, key findings, limitations, and conclusions.

Data Synthesis and Analysis

This is the core of the literature review, where you not only summarize but also integrate findings from multiple studies: **Identify Themes:** Group findings based on themes, concepts, or categories that emerge from the data; **Compare and Contrast:** Highlight similarities and differences among findings from different studies; **Identify Gaps:** Point out areas where research is lacking, results are contradictory, or questions remain unanswered; **Evaluate Quality:** Critically assess the methodology and findings of the studies you reviewed (especially for systematic reviews).

Result and Discussion

The Problem-Based Learning (PBL) model is an innovative approach in education that places students at the center of learning and authentic problems as the primary catalyst for the learning process. Let's delve deeper into the concepts and key characteristics of PBL.

PBL Definition

Problem-Based Learning (PBL) is a learning model that places real, authentic problems as the starting point for learning (Trullàs et al., 2022; Silva et al., 2018). In PBL, students are confronted with complex, unstructured problems and actively engage in inquiry, research, and collaboration to find solutions. The primary goal is not simply to find the correct answer, but also to develop critical thinking, problem-solving, and independent learning skills. This differs significantly from traditional approaches, which often present theory first and then provide practice problems.

Key Characteristics of PBL

PBL has several key characteristics that distinguish it from other learning models: **Student-Centered:** In PBL, the teacher acts as a facilitator or guide, not the sole source of information. Students take responsibility for their own learning, actively seeking, analyzing, and synthesizing information; **Based on Real and Relevant Problems:** The problems presented in PBL are not simple exercises, but rather complex scenarios that reflect real-world challenges. This relevance makes students more motivated and see the meaning of what they are learning; **Encourages Independent Inquiry and Discovery:** Students are encouraged to conduct their own research, identify what they need to learn (learning issues), and seek resources to solve problems. This builds independent learning; **Involves Group Work and Collaboration:** PBL is often conducted in small groups. Students learn to discuss, share ideas, listen to other perspectives, and collaborate to reach solutions, thus developing social and communication skills; **Fosters the Development of Problem-Solving Skills:** The essence of PBL is to train students to confront problems, analyze them, identify various approaches, and formulate logical and reasoned solutions. These are crucial skills for life; **Encourages Reflection and Self-Evaluation:** After the problem-solving process is complete, students are encouraged to reflect on their learning, evaluate the effectiveness of the solutions they found, and identify areas for future improvement. This helps them become better learners (Maqsood et al., 2025).

PBL Stages

While implementation can vary, PBL generally follows a series of stages: **Orienting Students to the Problem:** The teacher presents an interesting and relevant problem to students. This problem should be complex enough to spark curiosity and inquiry; **Organizing Students for Learning:** Students are broken into small groups. The teacher helps the groups define the problem, identify what they already know, and what they need to learn; **Guiding Individual and Group Inquiry:** Students begin investigating the problem independently or in groups. They seek information from various sources (books, the internet, expert interviews), analyze data, and develop hypotheses.

The teacher facilitates this process, provides direction, and ensures students stay on track; **Developing and Presenting Results:** After the investigation, groups formulate solutions or conclusions to the given problem. They then present their work in various formats, such as presentations, reports, posters, or models, to the class; **Analyzing and Evaluating the Problem-Solving Process:** The teacher and students jointly evaluate the presented solutions, discuss their effectiveness, and reflect on the learning process they

have gone through. This stage is crucial for identifying the strengths and weaknesses of their approach and for learning from experience. By understanding these concepts and characteristics, we can see how PBL is a powerful tool for not only teaching content but also shaping students into effective critical thinkers and problem solvers (Rehman et al., 2024; Liu & Pásztor, 2022).

PBL Mechanisms for Enhancing Critical Thinking

PBL is inherently designed to stimulate and develop various aspects of students' critical thinking skills through a series of challenging and authentic activities: Problem Identification and Analysis: When faced with an unstructured problem, students are forced to analyze the situation. They learn to identify the core of the problem, break it down into smaller sub-problems, and determine what information is relevant or needed to solve it. This process is the foundation of critical thinking; Hypothesis Development and Inference: In an effort to understand the problem, students are encouraged to formulate initial guesses (hypotheses) about the cause or solution to the problem. This trains their inference skills, namely drawing tentative conclusions based on limited initial information. They learn to think beyond the immediately obvious; Information Evaluation: To solve a problem, students must seek and gather information from various sources. This is where evaluation skills are essential. Students must select credible sources, assess the reliability of the data, critique potential biases, and determine the relevance of the information to the problem at hand; Argument Formation and Explanation: After gathering and analyzing information, students must construct a coherent argument to support their solution or conclusion. They are trained to provide clear and logical explanations of how they arrived at the solution, supported by strong evidence and reasoning. This often involves group discussions and debates, which sharpen their argumentative skills (Liu & Pásztor, 2022).

Decision-Making

PBL often requires students to choose the best solution from several possible alternatives. This process forces them to conduct a thorough analysis and evaluation of each option, considering potential impacts, risks, and benefits, before making the most rational decision based on the available evidence. Metacognition (Self-Regulation) (Markula & Aksela, 2022): Throughout the PBL process, students are encouraged to reflect on how they learn and solve problems. They ask themselves, "Is this strategy effective?", "Did I miss something?", or "How can I learn better?" This self-regulation process allows them to monitor and adjust

their thinking approaches, identify strengths and weaknesses, and continuously improve their critical thinking skills in the future.

Thus, PBL is not just a teaching method, but a framework that systematically facilitates and hones students' critical thinking skills through direct experience in facing and solving real-world problems (Almulla, 2020; Arviani et al., 2023).

Implementing PBL in Biodiversity

The Problem-Based Learning (PBL) model is very effective when applied to biodiversity (Komala et al., 2021). This material, which is often considered complex, actually provides fertile ground for PBL to stimulate students' critical thinking.

Reasons for Selecting Biodiversity

There are several compelling reasons why biodiversity is well-suited for PBL implementation (Pary et al., 2025).

Complex Material rich in Contextual Issues

Biodiversity is not simply a list of species names or taxonomic classifications. This material covers highly relevant and pressing real-world issues, such as environmental degradation, species extinction, and conservation efforts. These issues are multidimensional, involving ecological, social, economic, and ethical aspects, making them ideal for stimulating in-depth thinking. Real-world problem development points relevant to students' lives: Many biodiversity issues occur in students' immediate surroundings, such as river contamination, land conversion, or poaching. This allows teachers to design problem scenarios that are authentic and relevant to students' experiences, thereby increasing their engagement and motivation to learn. Requires conceptual understanding, not just memorization: To fully understand biodiversity, students cannot simply memorize. They must understand concepts such as food webs, ecological succession, adaptation, and the impacts of human activities. PBL encourages students to construct this understanding through active inquiry, rather than passively receiving information (Novalia et al., 2025; Sánchez-García & Reyes-de-Cózar, 2025).

Example Problem Scenarios (Case Studies)

Problem scenarios are the heart of PBL. Here are some examples that can be applied to biodiversity material:

Example 1: The Problem of Deforestation in a Specific Region and Its Impacts

This scenario can begin with news or data about the rate of deforestation in a specific region (e.g., forests in

Sumatra or Kalimantan). Students are asked to analyze the causes of deforestation (e.g., palm oil plantations, mining, encroachment), its impacts on local biodiversity (e.g., habitat loss, orangutan/tiger extinction, microclimate change), and suggest realistic and sustainable conservation solutions (e.g., reforestation, government policy, community education, ecotourism).

Example 2: Invasive Alien Species Introduction:

This problem could be the discovery of a non-native predatory fish in a local lake or an invasive plant that is destroying the native ecosystem. Students investigate this phenomenon, determine how the species was introduced, its impact on native species and the ecosystem's balance, and develop effective mitigation strategies (e.g., population control, public education to prevent the release of non-native species).

Example 3: The Dilemma between Economic Development and Biodiversity Conservation

This scenario could be a proposed mine development in an area known for its rich biodiversity, or an infrastructure project that cuts through a national park. Students are faced with an ethical and economic dilemma: how to balance the need for development with the urgency of conservation. They are asked to analyze the advantages and disadvantages of each side, identify stakeholders, and propose compromise solutions or alternatives that can minimize negative impacts on the environment.

Classroom Implementation Steps

The implementation of PBL in biodiversity follows the general stages of PBL

Student Orientation to the Problem (Scenario Presentation)

The teacher presents an interesting and challenging problem scenario (such as the example above) to students. This scenario should be presented clearly, spark curiosity, and encourage students to start thinking. This can be through a video, news article, statistical data, or a live presentation.

Organizing Study Groups

Students are divided into small groups (ideally 4-5 students). Each group will work together to solve the problem. The teacher explains the role of each group member and the importance of collaboration.

Guided Inquiry (Information Search, Data Collection)

Groups begin analyzing the problem, identifying "what they already know" and "what they need to find out" (the learning problem). They then conduct independent investigations by seeking information from various sources (textbooks, scientific journals, the internet, interviews with experts, field data). The teacher

acts as a facilitator, providing guidance, asking prompting questions, and ensuring students stay on track (Darling-Hammond et al., 2020; Crogman & Trebeau Crogman, 2018).

Benefits and Challenges of Implementing PBL

The implementation of the Problem-Based Learning (PBL) model offers significant benefits (Wang, 2021; Wijnia et al., 2024; Guo et al., 2020), but it also presents a series of challenges that need to be anticipated and addressed. Understanding both aspects is crucial for successful implementation.

Benefits of Implementing PBL

PBL is designed not only to impart knowledge but also to develop essential 21st-century skills. Here are the main benefits:

Significant Improvement in Critical Thinking Skills

This is the most prominent benefit of PBL. By imagining complex, real-world problems, students are encouraged to analyze information, generate various options, formulate hypotheses, and construct logical arguments. This process directly develops their critical thinking skills.

Increased Student Motivation and Engagement:

Authentic, life-relevant problems make learning more engaging and meaningful. Students feel a sense of purpose, rather than simply memorizing facts, which increases their motivation and active participation in class.

Development of Collaboration and Communication Skills:

PBL often involves group work. Students learn to interact, share ideas, listen to others' perspectives, negotiate, and achieve context. This effectively fosters collaboration and communication skills that are essential for future success.

Developing a Deeper and More Durable Conceptual Understanding:

Rather than simply memorizing, students in PBL construct their own understanding through exploration and problem-solving (Mutanga, 2024; Lenkauskaitė et al., 2021). This understanding, developed through hands-on experience, tends to be stronger, deeper, and more easily remembered in the long term.

Developing Independent Learning:

Because students must actively seek information and solve problems on their own, they are trained to become self-directed learners (Mayombe, 2025; Almomani et al., 2023; Arifin et al., 2025). They learn to

identify what they need to know, how to find it, and how to use that information effectively.

Challenges of PBL Implementation

Despite its many benefits, PBL implementation is not without several challenges that require careful attention and appropriate strategies (Chen et al., 2021; Zhang & Ma, 2023).

Requires More Preparation Time for Teachers

Designing authentic and relevant problem scenarios, and developing guides and resources that support student inquiry, requires a significant investment of time from teachers compared to traditional teaching methods (Muhamad Dah et al., 2024). Teachers also need to prepare themselves to act as facilitators, not just lecturers.

Not All Students Adapt to This Learning Model Immediately

Students accustomed to lectures and memorization may initially feel uncomfortable or overwhelmed by the freedom and responsibility afforded by PBL (Ssemugenyi, 2023). They may need extra time and guidance to adapt to their active role in learning.

Requires Adequate Learning Facilities and Resources

Effective PBL implementation often requires access to a variety of information sources (books, the internet, journals, data), facilities for group work, and possibly tools or materials for experiments or simulations (Fitrah et al., 2025; Nicholus et al., 2024). The availability of these facilities and infrastructure can be a challenge in some institutions.

More Complex Assessment:

Assessing student progress in PBL focuses not only on final answers, but also on problem-solving processes, collaboration skills, critical thinking skills, and independent learning (Putri et al., 2024). This requires more diverse and comprehensive assessment instruments (e.g., rubrics, formative assessments, performance assessments, observations), which can be more complex to design and implement than multiple-choice tests. Despite the challenges, with careful planning, adequate teacher training, and institutional support, the benefits of PBL in shaping students into critical thinkers and lifelong learners far outweigh the difficulties of implementation (Wahdaniyah et al., 2023; uniantari & Suniasih, 2023).

Conclusion

Based on the explanation above, it can be concluded that the Problem-Based Learning (PBL) model has proven highly effective in optimizing high school

students' critical thinking skills, particularly when applied to biodiversity. Through PBL, students are not simply encouraged to memorize concepts but are also encouraged to analyze, evaluate, draw inferences, and explain solutions to complex, real-world environmental problems. Fundamentally, PBL empowers students to become active problem solvers and critical thinkers. They are no longer passive recipients of information but instead become key actors in an independent, collaborative, and reflective learning process. Thus, PBL not only enhances academic understanding but also equips students with essential cognitive skills much needed in the modern era.

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Author Contributions

Conceptualization; methodology; validation; formal analysis; R. T. T.; investigation; resources; data curation; A. L.; writing – original draft preparation; writing – review and editing; S. J.; visualization: R. D. A. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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