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The development of critical thinking in grade 11 biology students through problem-based learning with forensic science issues

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ABSTRACT

Critical thinking is crucial for biology education and requires an instructional method that allow learners to acquire the skill through hand-on experiences with content related to learners' lives. This action research aimed to enhance the critical thinking skills of Grade 11 students using problem-based learning (PBL) integrated with forensic science issues in a biology course on the circulatory system. The study was developed in an action research design. The study involved 12 students from a public school in the Thai educational context. The research instruments included a PBL learning management plan, a critical thinking assessment, and an interview form. Data analysis showed that in the first cycle, the average critical thinking score was 67.08%, with 58.33% of students meeting the 70% threshold. After revising the learning activities, the second cycle showed an average score increase to 83.75%, with all students surpassing the 70% threshold. These findings contribute to the research area by demonstrating the effectiveness of integrating PBL with forensic science to enhance critical thinking skills in biology education. The implementation of PBL with forensic science issues should be more investigated in other topics.

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1. INTRODUCTION

Scientific process is crucial for students in working and living in the complex society. In order to do scientific examinations in class, students must engage in the process of observation, hypothesis formulation, experiment planning, data collection, result analysis, and findings summarization (Driver et al., 1994). These processes require methodical reasoning, analytical aptitude, and critical thinking capabilities. Critical thinking is a self-guided, self-disciplined thinking that strives to reason at the highest level of quality in a fair-minded way, which is crucial for students learning science (Santos, 2017). It enables them to evaluate information rigorously, draw logical conclusions, and solve complex problems. Consequently, it is no surprise that this skill is included in the expected outcomes of science education worldwide (Miterianifa et al., 2021; Saleh et al., 2021).

Moreover, in the processes of biology instruction, students are expected to understand living organisms, biological processes, and diversity, as well as the impact of technology on humans and the environment (Kampourakis & Reiss, 2018; Reiss & Winterbottom, 2021). This requires studying data, principles, processes, and learning steps, necessitating careful thinking, analysis, and interpretation of content. It involves evaluating facts and opinions before making reasonable conclusions (Martputorn & Art-in, 2022). Consequently, critical thinking is vital in biology education. Schools also aim to develop students' careful, reasoned thinking processes, enabling them to assess situations and identify problems using intellect.

However, critical thinking remains a crucial component of science education in the Thai context. Scholars have highlighted that learners often struggle with thinking logically to support their experiments, leading to significant issues (Faikhamta et al., 2018; Yuenyong & Narjaikaew, 2009). The lack of critical thinking in science education results in students making poorly reasoned conclusions, failing to understand complex concepts, and being unable to apply scientific principles effectively. This deficiency affects their problem-solving abilities and hinders their overall scientific literacy (Yuenyong & Narjaikaew, 2009). The negative outcomes of this lack of critical thinking are evident in the performance of Thai students in both national and international assessments (National Institute of Educational Testing Service, 2022; OECD, 2022). Students consistently score below expectations, reflecting their inability to engage deeply with scientific content and apply critical analysis to real-world problems. This highlights the urgent need to improve critical thinking skills in science education to better prepare students for future academic and professional challenges.

The issues may arise from the prevalent passive learning environment employed in Thai education (Pholphirul et al., 2023). Practically in a passive classroom, teachers engage in verbal communication while students passively receive information; some actively record notes, while others get disengaged (David, 2018). The absence of practical exercises and tangible real-world connections renders the classes monotonous and devoid of interest. This is in opposition to the essence of critical thinking development, which necessitates active involvement and real-world implementation (Kooloos et al., 2020). Hence, employing instructional techniques that enable learners to address difficulties related to real-life scenarios could prove advantageous. Integrating additional interactive and immersive learning opportunities could allow students to enhance their critical thinking abilities more efficiently and experience the learning process as more significant and captivating.

Considering the circumstances in this context, problem-based learning could provide a potential solution. Problem-based learning is an instructional approach where students acquire knowledge by actively engaging in the process of solving complex, open-ended problems (Barrows, 1986; Barrett, 2017; Savery, 2019; Schmidt et al., 2019; Servant-Miklos et al., 2019). This technique redirects the emphasis from conventional teacher-led instruction to student-initiated inquiry. Problem-based learning involves students being given authentic, open-ended challenges that do not have a predetermined answer. This approach stimulates students to conduct research, work with others, and apply their knowledge in order to discover solutions (Kooloos et al., 2020).

Moreover, as PBL involves solving problems, using real-world situations that capture learners' interest can be an effective way to keep students engaged. Integrating scientific forensic issues into PBL could create scenarios that not only engage students but also enhance their critical thinking skills in biology classes. The previous studies urge to add in be element that could make PBL suite the nature of participants' learning. Therefore, this study aims to integrate scientific forensic issues into PBL to teach biology for grade 11 students.

2. LITERATURE REVIEW

2.1 Critical thinking in biology education

Critical thinking could be defined as the ability to analyze and evaluate information, reasoning, and situations to construct new knowledge, understandings, hypotheses, and beliefs. It involves processing and synthesizing information to apply it effectively in decision-making and problem-solving (Dressel & Mayhew, 1954; Paul, 1992; Limbach & Waugh, 2010; Pirozzi et al., 2013; Thornhill-Miller et al., 2023). According to the ACER framework (Heard et al., 2020), the principles of critical thinking could be outlined through three main strands: Knowledge Construction which involves identifying gaps in knowledge, discriminating among information, and identifying patterns to make connections, evaluating reasoning - applying logic, identifying assumptions and motivations, and justifying arguments, and decision-making that includes identifying criteria for decisions, evaluating options, and testing and monitoring implementation.

Facione (2011) labelled needed skills in critical thinking namely interpretation, analysis, evaluation, inference, explanation, and self-regulation. Interpretation involves understanding and expressing the significance of various data and situations. Analysis focuses on identifying relationships among ideas and arguments. Evaluation assesses the credibility and logical strength of statements and arguments. Inference draws logical conclusions from available information. Explanation entails presenting and justifying one's reasoning coherently. Self-regulation involves monitoring and correcting one's cognitive processes. These skills collectively enable individuals to process information rigorously and make well-informed decisions.

Critical thinking is crucial in biology education as it enables students to understand complex biological processes and concepts. It promotes systematic analysis, encourages rigorous evaluation of data, and fosters the ability to draw logical conclusions from experiments. This skill is essential for students to become proficient in scientific inquiry and to apply biological knowledge to real-world problems effectively. Integrating critical thinking into biology education helps students develop a deeper understanding of the subject, enhances their problem-solving abilities, and prepares them for advanced scientific studies and careers.

2.2 Critical thinking in scientific processes

Scientific processes involve several key steps: problem identification, information gathering, information organization, hypothesizing, and conclusion and decision-making (Driver et al., 1994). Problem identification is defining the specific issue or question to be addressed. Critical thinking helps in clearly articulating the problem to ensure a comprehensive understanding. In information gathering, critical thinking aids in discerning reliable sources and evaluating the quality of information. For information organization, critical thinking ensures logical arrangement and connection between data points. During hypothesizing, it supports generating plausible explanations based on the organized information. In conclusion and decision-making, critical thinking allows for the evaluation of evidence, weighing pros and cons, and justifying the chosen solution.

Thus, critical thinking enhances each step of the scientific process, leading to robust and reliable outcomes (Saleh et al., 2021; Santos, 2017). By fostering clarity in problem identification, critical thinking ensures that the research question is accurately defined. During information gathering, it aids in selecting credible sources and assessing the validity of data. In organizing information, critical thinking allows for logical structuring and pattern recognition. When hypothesizing, it supports the development of well-founded and plausible explanations. Finally, in conclusion and decision-making, critical thinking enables thorough evaluation of evidence and sound reasoning, resulting in justified and dependable solutions.

2.3 Problem-based learning

Problem-based learning is an educational approach where learning begins with a problem (Barrows, 1986; Savery, 2019; Schmidt et al., 2019;). The problem in this approach of teaching, often reflecting real-life scenarios, is carefully selected, and adapted to meet educational objectives (Barrett, 2017). The process emphasizes formulating questions rather than focusing solely on answers, relating learning content to context, which enhances student motivation and comprehension (Servant-Miklos et al., 2019; Prachagool & Nuangchalerm, 2021). PBL involves self-directed learning, where students often define their own problems within guidelines, building from their experiences and interests. This method requires active engagement in research and decision-making, promoting deeper learning. It integrates interdisciplinary perspectives, ensuring that students draw on diverse knowledge areas to solve problems (Schmidt et al., 2019). The approach also emphasizes exemplary practice, helping students transfer knowledge across different contexts. Finally, group-based learning is integral to PBL, fostering teamwork and collaboration (Savery, 2019).

Problem-Based Learning is characterized by several essential elements. The nature of the problem is central, with ill-structured problems that are ambiguous and have multiple solutions, promoting flexibility and complex thinking (Barrows, 1986). Context is crucial, embedding problems in relevant and rich scenarios to foster deep thinking and motivation. PBL integrates interdisciplinary knowledge, requiring diverse skills and perspectives. It follows a learner-centered approach, encouraging students to take responsibility for their learning. Lastly, the teacher's role is to guide and facilitate rather than provide direct instruction, supporting students' self-directed learning and problem-solving initiatives (Savery, 2019; Schmidt et al., 2019).

2.4 Previous studies

Recent research in biology education (e.g., Matawali et al., 2019; Priyadi & Suyanto, 2019; Bahri et al., 2021; Laksmi et al., 2021; Shamdas et al., 2023; Suwono et al., 2023; Xu et al., 2021), emphasizes the advantages of problem-based learning in attaining desired results in biology classrooms. For example, Bahri et al. (2021) provide evidence that problem-based learning promotes the growth of one's character, whereas Laksmi et al. (2021) illustrate improvements in scientific explanation abilities specifically pertaining to environmental subjects. Matawali et al. (2019) demonstrate that Problem-Based Learning (PBL) enhances the comprehension of science foundation students at a profound level. Priyadi and Suyanto (2019) discovered that PBL enhances critical thinking abilities by utilizing tools such as the Fishbone Diagram.

According to Shamdas et al. (2023), problem-based learning improves the communication abilities of high school pupils by including STEM-based biology lectures. The authors Suwono et al. (2023) highlight the significance of problem-based learning in advancing health literacy. Xu et al. (2021) validate the efficacy of problem-based learning in medical cell biology teaching by a comprehensive meta-analysis. These studies demonstrate how problem-based learning actively involves students, improves a range of skills, and equips them to tackle intricate real-world issues in the field of biology. Therefore, PBL is particularly beneficial because it allows students to face real-world problems and learn how to solve them using classroom knowledge. Scholars also advocate for integrating more cases that capture students' interest, ensuring the method's effectiveness.

2.5 Scientific forensic issues

For successful implementation of PBL, it is crucial to select problems that align with the learning needs and interests of the students (Barrows, 1986; Savery, 2019; Schmidt et al., 2019). For grade 11 students, who are in their adolescent years, engaging and stimulating contexts are essential. Given their exposure to real-world issues through various media, incorporating scientific forensic issues-specifically crime cases requiring forensic evidence-can be particularly effective. Addressing these complex problems allows students to hone their reasoning and evidence-based thinking skills, thereby enhancing their critical thinking abilities, which is the primary objective of this study.

In conclusion, critical thinking is vital for every scientific process in biology classes. Problem-based learning is an effective approach, and integrating scientific forensic issues may captivate students' interests. Consequently, this study integrates scientific forensic issues into PBL as a core principle to develop a learning management plan aimed at enhancing the critical thinking skills of grade 11 students. The primary goal of the study is to examine the effectiveness of this integrated PBL approach on improving critical thinking in biology classrooms for these students.

3. METHOD

3.1 Research design

The study adhered to the principles of action research as proposed by Kemmis et al. (2014a, 2014b). An expected outcome was set, and a preliminary test was administered. Students who did not meet the expected outcome threshold were selected as participants, and only their scores were included in the study results. A learning management plan comprising eight topics, detailed in sub-lesson plans, was developed. Topics 1-4 were covered in learning cycle 1, followed by an assessment of students' critical thinking skills and a discussion of the results. The learning activities were then revised based on these findings and used again for teaching topics 5-8. This iterative process aimed to refine the teaching approach and enhance critical thinking outcomes.

3.2 Participant

A class of Grade 11 students from a public school in the Thai educational context was selected for the study. After a preliminary test, 12 students who did not achieve the expected score were chosen as participants. Ethical considerations in human research were adhered to throughout the study.

3.3 Instrument

Problem-based learning with an integration of scientific forensic issues plan

A learning management plan was developed based on classroom management principles (Evertson & Weinstein, 2006; Oliver & Reschly, 2007; Klattenberg, 2021). The plan includes purposes, content, learning objectives, learning activities, learning materials and resources, and assessment methods. The learning activities were designed using PBL integrated with scientific forensic issues. Problems related to forensic cases were introduced in class, and students used their classroom knowledge to solve them. The content focused on the cardiovascular system, including the heart and blood. Students discussed solving forensic cases using their understanding of the cardiovascular system, applying their class-learned knowledge. The plan was implemented over 12 class hours and evaluated to be at a qualified and appropriate level by a group of five scholars in pedagogy and professional teachers. The details of the activities in the learning management plan can be seen in Table 1.

Table 1 Learning management plan activities

	Learning topics	Scientific forensic issues
Learning cycle 1	Heart Structure	"The Mystery of the Dead Woman in the Fruit Warehouse"
	Heart Function	"Uncovering the Truth: Deputy Inspector Dies in His Room"
	Blood Vessels	"Nurse's Love Tragedy: Suspected Poison Injection Suicide"
	White Blood Cells	"Rescue Worker Dies in Rental Room: Suspected Seafood Allergy!"
Learning cycle 2	Red Blood Cells	"Three Tourists Die in Tent at Doi Inthanon National Park"
	Platelets and Plasma	"Tragic! Bride Dies from Uncontrolled Bleeding After Dental Cleaning"

	ABO Blood Group System	"Hospital Suspected of Wrong Blood Type Transfusion Leading to Death During Surgery"
	Rh Blood Group System	"Tragedy: 24-Year-Old Woman Dies from Hemorrhage in Chiang Mai Bathroom"

Critical thinking test

A 20-item multiple-choice test, each with 4 options and based on scenarios was developed. The test framework follows Dressel & Mayhew's (1957) model, comprising defining problems, gathering information, organizing information, selecting hypotheses, and making conclusions and decisions. Five experts assessed its content validity using the index of item objective congruence, leading to necessary revisions. The test was trialed with different group of students in the same school, yielding difficulty (p) values of 0.25-0.64 and discrimination (r) values of 0.21-0.36. The final 20-item test had a KR-20 reliability of 0.89 and was used at the end of each operational cycle.

Interview form

Semi-structured interviews were conducted with students who did not meet the 70% threshold at the end of each learning cycle. The interviews focused on critical thinking, student opinions on learning activities, and feedback on the teacher. Summaries from these interviews were used to refine subsequent learning cycles. Five experts reviewed the interview protocol, and the interview form was revised following the comment prior to the implementation.

3.4 Data collection and data analysis

The research followed an action research model (Kemmis & McTaggart, 1988) with two learning cycles, each encompassing planning, action, observation, and reflection stages. Initially, critical thinking issues among grade 11 students were identified, and those scoring below 70% on the critical thinking test were selected as participants. The plan was executed over two cycles, each with four lessons on cardiovascular and blood-related topics. Students' behaviors and critical thinking skills were observed and assessed. Based on these evaluations, the learning activities were refined for the subsequent cycle to enhance critical thinking skills effectively. The numerical data were analyzed using percentage, mean score, standard deviation while qualitative data were analyzed using content analysis.

4. RESULT AND DISCUSSION

The results from the two learning cycles of action research aimed at developing critical thinking skills in 12 target students through problem-based learning combined with forensic science issues, ensuring they achieved at least 70% of the total score. The summary of students who met or did not meet the 70% threshold is illustrated in Figure 1.

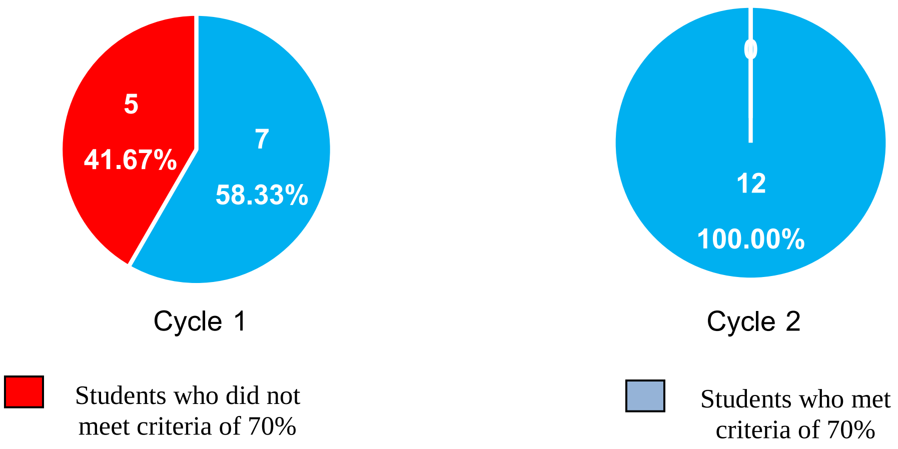

Figure 1 Summary of the learning cycle

Figure 1 shows that, following the first cycle of problem-based learning with forensic science issues, 7 out of the 12 target students (58.33%) achieved scores above the 70% threshold, while 5 students (41.67%) did not. After the second cycle, all 12 target students (100%) surpassed the 70% threshold. The analysis of the target students' critical thinking test scores, in comparison to the 70% benchmark, is detailed in Table 2.

Table 2 The detail of participants' critical thinking test scores in 2 learning cycles

Learning cycle	Components of critical thinking					Overall (20)
	Defining problems (4)	Gathering information (4)	Organizing information (4)	Selecting hypotheses (4)	Making conclusions and decisions (4)	
1	3.17 (79.17%)	2.33 (58.33%)	2.83 (70.83%)	2.92 (72.92%)	2.17 (54.17%)	13.42 (67.08%)
2	3.75 (93.75%)	3.17 (79.17%)	3.33 (83.33%)	3.42 (85.42%)	3.08 (77.08%)	16.75 (83.75%)

From Table 2, during the first operational cycle, the overall average score for all components of critical thinking was 13.42, equivalent to 67.08%. When examining the average scores for each component, each out of a maximum of 4 points, the highest percentage was for problem definition, with an average score of 3.17 (79.17%). This was followed by hypothesis selection (2.92, 72.92%), information organization (2.83, 70.83%), information gathering (2.33, 58.33%), and the lowest was conclusion and decision-making (2.17, 54.17%), as shown in Figure 2.

In the second operational cycle, the overall average score for all critical thinking components was 16.75, or 83.75%. When considering the average scores for each component, the highest percentage was again for problem definition, with an average score of 3.75 (93.75%). This was followed by hypothesis selection (3.42, 85.42%), information organization (3.33, 83.33%), information gathering (3.17, 79.17%), and the lowest was conclusion and decision-making (3.08, 77.08%). Notably, all components of critical thinking had average scores exceeding the 70% threshold, as illustrated in Figure 2.

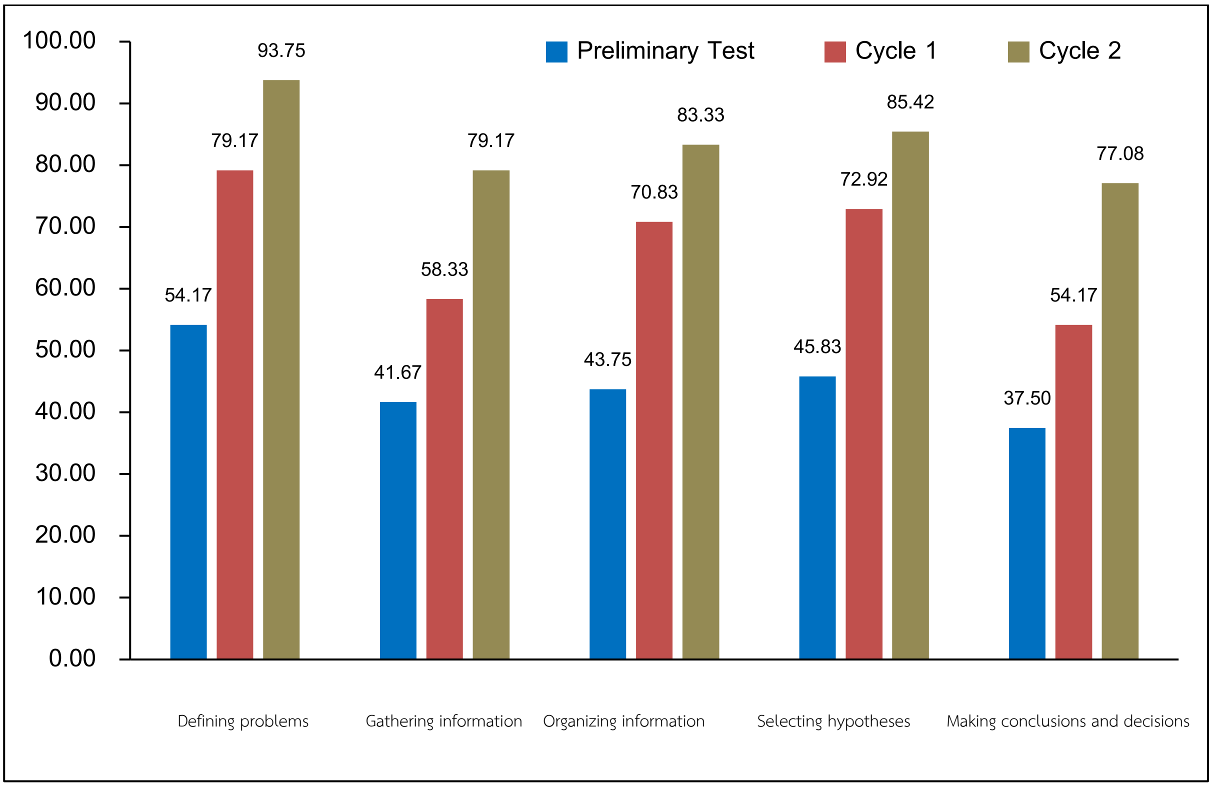

Figure 2 The detail of participants' critical thinking test scores

The analysis indicated that students showed improvement in critical thinking after instruction, with an average score of 13.17 out of 20 (67.08%). Individually, 7 students (58.33%) surpassed the 70% threshold, while 5 (41.67%) did not. The highest average score was in problem definition (79.17%), followed by hypothesis selection (72.92%), information organization (70.83%), information gathering (58.33%), and the lowest in conclusion and decision-making (54.17%). The PBL approach, incorporating forensic issues, used challenging scenarios to engage students in analyzing and solving ambiguous forensic problems, thereby enhancing their critical thinking through discussion and evidence-based reasoning.

Despite improvements, 5 students scored below 70%. Interviews revealed difficulties in independent research and evaluating information reliability, compounded by limited class time and complex content. These issues led to incomplete data collection and less reliable conclusions, affecting the scores in conclusion and decision-making.

After refining the learning activities, the average critical thinking score rose to 16.75 out of 20 (83.75%), with all students meeting the 70% threshold. Problem definition scored highest (93.75%), followed by hypothesis selection (85.42%), information organization (83.33%), information gathering (79.17%), and conclusion and decision-making (77.08%).

Improvements included stimulating analytical thinking with questions, encouraging students to define problems and hypotheses, and fostering group discussions to enhance information organization.

The PBL approach, integrated with forensic issues, effectively promotes critical thinking by engaging students in self-directed learning and evidence-based problem-solving. This aligns with studies by Sholihah & Lastariwati (2020) and Suryanti & Nurhuda (2021), which found that PBL enhances critical thinking skills. With more time, these skills could be further developed, particularly in conclusion and decision-making (Hacıoğlu & Gülhan, 2021; Khajornkhae & Nuangchalerm, 2021).

The results of the study also indicate the benefits of PBL in biology education. Findings align with previous investigations (e.g., Bahri et al., 2021; Laksmi et al., 2021; Matawali et al., 2019; Priyadi & Suyanto, 2019; Xu et al., 2021; Shamdas et al., 2023; Suwono et al., 2023; Thaochalee & Nuangchalerm, 2023) that also discovered similar results. This is because PBL promotes active learning, critical thinking, and the application of knowledge to real-world scenarios. When students engage in problem scenarios, they actively participate in the learning process, apply theoretical concepts to practical situations, and develop essential critical thinking skills. With the integration of scientific forensic issues as problems, the approach becomes more engaging and relevant to students, and also sparking their interest and motivation.

5. CONCLUSION

The study investigated the effects of problem-based learning on the critical thinking skills of grade 11 students in the context of biology scientific processes. It employed an action research approach with two learning cycles, each encompassing planning, action, observation, and reflection stages. The results indicate that PBL positively impacted participants' critical thinking abilities, particularly in defining problems, gathering information, organizing information, selecting hypotheses, and making conclusions and decisions. The results of this study have several implications for pedagogy, academia, and policy making. Pedagogically, the positive impact of PBL on critical thinking suggests that integrating real-world problems, such as forensic issues, can enhance student engagement and learning outcomes. Academically, the findings provide evidence supporting the inclusion of PBL in science curricula to develop essential critical thinking skills, thus preparing students for higher education and scientific careers. For policy making, the study highlights the need for educational policies that promote innovative teaching methods like PBL, ensuring that students acquire critical thinking skills necessary for the 21st century.

While the study successfully demonstrated the benefits of PBL on enhancing critical thinking skills among grade 11 students, it has some limitations. The small sample size of 12 students restricts the generalizability of the results. Additionally, the study lacked data from the instructor's perspective, which could have provided valuable insights into the teaching process and the challenges faced during implementation. Addressing these limitations in future research by including larger samples and instructor feedback will provide a more comprehensive understanding of PBL's effectiveness.

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