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The Effectiveness of Problem-Based Learning Model in Improving Students' Critical Thinking Skills in Biotechnology Material

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ABSTRACT

Students must possess the essential 21st-century skill of critical thinking, especially in the study of biotechnology, which includes more complicated subject matter and contextual topics like GMOs and bioethics. The use of traditional learning methods, which are still the norm, is less effective in fostering these skills because there is little student participation. Problem-Based Learning (PBL) is an innovative solution that emphasizes real-world problem-based learning that is both collaborative and exploratory. The purpose of this study is to determine how well the PBL model improves students' critical thinking skills in biotechnology topics. The study, which included two XI IPA classes at Satya Dharma Jember High School, employed a quantitative approach with a quasi-experimental design (pretest-posttest control group design). The experimental class (32 students) received PBL-based education, while the control class (32 students) received instruction using traditional methods. A test of critical thinking skills based on Ennis' indicators is the tool utilized. The findings revealed a notable improvement in both groups, with the experimental group scoring higher (24.50 points) than the control group (12.25 points). The paired sample t-test revealed a notable improvement ($p < 0.05$), while the independent sample t-test showed a significant difference between the groups ($t = 4.78$; $p = 0.000$). According to this study, PBL is successful in fostering critical thinking skills because it provides an active, contextual, and reflective learning experience. As a result, PBL is advised as a learning technique for subjects like biotechnology that require critical thinking.

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1. INTRODUCTION

In learning in the 21st century, critical thinking skills are a very important and urgent provision to be mastered by every individual. This is because the rapid advancement of technology, the development of very complex information, and various global challenges covering social, economic, and environmental aspects require humans to be able to filter information carefully and make decisions appropriately (Facione, 2011). Critical thinking is a cognitive process that is not only purposeful but also reflective, which helps a person make wise decisions, based on evidence, and considers various possibilities before taking action (Paul, 2014). In the world of education, critical thinking is not just an end goal, but a fundamental skill that must be instilled early on because it can support a deeper understanding of concepts, the development of scientific reasoning, and the ability to solve complex problems independently (Halpern, 2014).

Critical thinking skills include several important aspects, such as the ability to analyze and evaluate information objectively, assess the quality of arguments presented, recognize bias or assumptions hidden behind a statement, make logical conclusions, and consider various points of view before making a final decision (Ennis, 2011). In the context of 21st century education, it is expected that students will not only master knowledge and subject matter, but will also be able to think reflectively and creatively in dealing with various problems that exist in the real world, so that they can become adaptive and innovative individuals (Trilling, 2009). This ability is very crucial considering that today's world is full of rapid change and uncertainty, so critical thinking skills serve as an important foundation for success in learning and life.

In the context of biology learning, especially in biotechnology material, critical thinking skills play a very important role. Biotechnology is a multidisciplinary applied science field, combining various principles of biology, chemistry, technology, and ethics, to produce products or services that provide benefits to human life (Campbell, 2021). Biotechnology material not only focuses on scientific theories, but is also related to contemporary issues that are developing in society, such as genetic engineering, mRNA vaccine production, cloning techniques, the use of genetically engineered organisms (GMO), as well as bioethical aspects concerning morals and social impacts (Nicholson, 2019). Therefore, students do not just have to memorize biotechnology concepts, but must be able to develop high-level thinking skills that can be used to analyze, evaluate, and make decisions based on a balanced scientific and ethical perspective (Sadler, 2004).

However, the reality on the ground shows that biotechnology learning in high schools is still often carried out in conventional ways. Learning relies more on lecture methods or direct instruction which makes teachers the main and only source of information (Sari, 2020). This kind of learning model has proven to be less effective in encouraging students to play an active role, think critically, and discuss in depth (McKeachie, 2013). As a result, students tend to be passive and just memorize the material, without getting a deep and continuous learning experience. This makes it difficult to develop much-needed critical thinking skills, especially those related to exploration and solving real problems (Brown, 2014).

To overcome these challenges, it is necessary to implement innovative learning models that can guide students to become active, critical and independent learners. One of the learning models that has been proven effective is Problem-Based Learning (PBL). PBL is a constructivist learning approach that emphasizes learning that is centered on real and complex problems that require investigation, collaboration, and reflection (Hmelo-Silver, 2004). In PBL, students are involved from the beginning to understand and identify problems, then conduct in-depth investigations through group discussions and systematic problem solving (Barrows, 1996). This approach is very much in line with the principles of social constructivism which emphasize the importance of social interaction and active involvement of students in constructing knowledge and meaning.

The teaching and learning process takes place through several systematic stages, starting from recognizing the problem, identifying the information needed, collecting and analyzing data, compiling appropriate solutions, to presenting and evaluating the results obtained (Savery, 2006). Through these stages, students are not only trained to think critically in depth, but also learn to work in teams and develop metacognitive skills, namely the ability to monitor and regulate their own thinking processes (Schraw, 1994). Various studies have shown that the application of PBL in science and biology learning can significantly improve students' critical thinking skills, creativity, and learning motivation (Aisyah, 2022).

The PBL learning model is ideal for application in biotechnology subjects. Topics in the field of biotechnology are usually complex and closely related to everyday life and often cause differences of opinion in society (Sadler, 2004). This condition actually provides an excellent opportunity for students to think more critically and deeply, and to see a problem from various different perspectives (Dewi, 2023). With this approach, students not only memorize biotechnology theories but are also able to consider the impacts of various aspects, such as science, social, economic, and moral, related to the technology (Khan, 2022). Based on these reasons, this study was conducted to see to what extent the Problem-Based Learning (PBL) model can hone students' critical thinking skills, especially in biotechnology material at the high school level.

2. RESEARCH METHOD

This study uses a quantitative approach with a quasi-experimental design type, which aims to test the effectiveness of the Problem-Based Learning (PBL) model on improving students' critical thinking skills. The design used in this study is a pretest-posttest control group design, where there are two treatment groups, namely the experimental group and the control group, each of which is given a test before and after the treatment to measure changes in critical thinking skills quantitatively and comparatively. The subjects in this study were class XI MIPA students at SMA Satya Dharma Jember in the 2024/2025 academic year. The determination of subjects was carried out purposively based on considerations of academic homogeneity**,** which was measured using students' average semester report card scores in biology and diagnostic pretest results that showed no significant difference between groups ($p > 0.05$). The selection also considered ease of access and class scheduling. The total number of research subjects was 64 students, who were divided into two groups randomly: 32 students in the experimental class who received learning treatment with the PBL model, and 32 students in the control class who received learning using conventional methods (lectures and question-and-answer sessions). The PBL treatment was implemented for four weeks (equivalent to six meetings, 2 × 45 minutes each). Each meeting in the experimental group followed the PBL syntax developed by Hmelo-Silver (2004): (1) problem orientation, (2) organizing students for learning, (3) guiding individual and group investigations, (4) developing and presenting solutions, and (5) analyzing and evaluating the problem-solving process. Examples of PBL activities included presenting authentic biotechnology problems (e.g., ethical issues in genetic engineering), group discussions to formulate hypotheses, data searches from various scientific sources, and collaborative presentations of findings. Meanwhile, in the control class, learning was carried out conventionally through teacher-centered lectures, explanation of concepts, and individual question-and-answer sessions, with limited student exploration or problem investigation. The main instrument used in this study was a critical thinking skills test compiled based on indicators developed by Ennis (1996), covering five main aspects: (1) providing simple explanations (elementary clarification), (2) building basic skills (basic support), (3) drawing conclusions (inference), (4) providing further explanations (advanced clarification), and (5) arranging strategies and tactics (strategies and tactics). The test questions were in the form of essays to provide space for students to express their thoughts logically, systematically, and argumentatively. The validity of the instrument content was consulted with experts, while the reliability test was conducted through a trial (*try out*) and analyzed using the Cronbach's Alpha formula. To analyze the test result data, two types of statistical tests were used. First, a paired sample t-test was used to determine whether there was a significant increase between the pretest and posttest scores in each group. Second, an independent sample t-test was used to test the difference in posttest results between the experimental and control groups, with the aim of comparatively assessing the effectiveness of the PBL model. All statistical analyses were performed using the latest version of SPSS software, and the significance level was set at $\alpha = 0.05$. The selection of this method follows the guidelines of Fraenkel (2019), which state that quasi-experimental designs—especially pretest-posttest control group designs, are highly suitable for assessing the effects of educational interventions when random grouping is not possible. This approach allows researchers to exercise relatively good control over external variables and draw stronger conclusions regarding the causal relationship between the independent variable (PBL model) and the dependent variable (critical thinking skills).

3. RESULT AND DISCUSSION

This study aims to determine the effectiveness of the Problem-Based Learning (PBL) model in improving critical thinking skills of grade XII IPA students in Biotechnology material. Data were obtained from the results of the pretest and posttest given to two classes, namely the experimental class (using the PBL model) and the control class (using the conventional model). A summary of the results of the average pretest and posttest scores of each group is presented in Table 1.

Table 1. Average Pretest and Posttest Scores of Students' Critical Thinking Skills

Group	Number of Students	Average Pretest Score	Avererage Posttest Score	Difference
Experimental (PBL)	32	56,25	80,75	24,50
Control	32	55,88	68,13	12,25

Table 1 shows that the average pretest scores of students' critical thinking skills in both groups were relatively balanced, namely 56.25 for the experimental group and 55.88 for the control group. However, after being given learning treatment, there was a significant increase in the average posttest scores in both groups, with the experimental group experiencing an increase of 24.50 points to 80.75, while the control group only experienced an increase of 12.25 points to 68.13. This indicates that although both learning methods are able to improve students' critical thinking skills, the Problem-Based Learning (PBL) model in the experimental group has a much greater impact compared to conventional learning in the control group.

Table 2. Paired Sample t-test Results (Pretest and Posttest for each group)

Group	t-count	Sig. (2-tailed)	Description
Experimental (PBL)	14,32	0,000	Sig. (p < 0,05)
Control	8,45	0,000	Sig. (p < 0,05)

Based on the results of the paired sample t-test in Table 2. shows that learning outcomes have increased significantly with students' critical thinking skills scores from pretest to posttest in each group. In the experimental group using the Problem-Based Learning (PBL) model, a t-count value of 14.32 was obtained with a significance value of 0.000, indicating that the increase in the score was statistically significant ($p < 0.05$). This indicates that the PBL model is effective in improving students' critical thinking skills. While in the control group using conventional learning, the t-count value of 8.45 with a significance of 0.000 also showed a significant increase, although the t-count value was lower than the experimental group. This means that conventional learning also has a positive effect, but the increase is not as large as the PBL model.

Table 3. Results of the Independent Sample t-test (Posttest between groups)

Group	t-count	Sig. (2-tailed)	Description
Eksperimental vs Control	4,78	0,000	Sig. (p < 0,05)

Based on Table 3. shows the results of the independent sample t-test used in comparing the posttest scores between the two groups. The test results show a t-count value of 4.78 with a significance value of 0.000, which indicates a statistically significant difference between the average posttest scores of the experimental group and the control group. In other words, students who learn using the PBL model have a higher increase in critical thinking skills than students who receive conventional learning.

Based on the data analysis results at Table 1, it is known that the average pretest scores of both groups are relatively equivalent, which are 56.25 for the experimental group and 55.88 for the control group. This equivalence indicates that the initial critical thinking abilities of both groups do not differ significantly. Therefore, it can be concluded that the differences in posttest results that emerged are a direct result of the treatment provided during the learning process. This condition is important to ensure the internal validity of the research, as stated by Fraenkel (2019) that the initial equivalence of groups is crucial in quasi-experimental research to objectively assess the effectiveness of the treatment.After being treated, there was a significant increase in posttest scores in both groups. The experimental group, which used the Problem-Based Learning (PBL) model, experienced an average increase of 24.50 points to 80.75, while the control group, which used conventional learning methods, only increased by 12.25 points to 68.13. This notable difference in improvement indicates that PBL is more effective in enhancing students' critical thinking skills. These findings are consistent with the study by Puspitasari (2023), which states that the application of PBL enhances critical thinking skills through a learning process that emphasizes real problem-solving, collaboration, and deep reflection on information.The strengthening of these findings is also shown by the results of the paired sample t-test at Table 2, where there was a significant increase in critical thinking skills scores in both groups with a significance value of $p = 0.000$ ($p < 0.05$). However, the t-calculated value in the experimental group (14.32) is much higher than in the control group (8.45), indicating that the PBL model has a stronger effect on improving critical thinking skills. This is further supported by recent meta-analysis studies by Strobel (2020) and updated by Sunarto and Fitriyani (2023), which show that problem-based learning results in significant improvements in students' analytical, evaluative, and reflective abilities compared to traditional learning.

The comparison of posttest results between groups through the independent sample t-test at Table 3 shows a significant difference ($t = 4.78$; $p = 0.000$), indicating that the PBL model is substantially more effective than the conventional approach. This is because PBL positions students as active subjects in the learning process, emphasizing teamwork, exploration of authentic problems, and the development of solutions based on data and logic. Khan (2022) asserts that this approach fosters a systematic and holistic critical mindset. In the context of Biotechnology learning, which involves complex topics such as genetic engineering, food biotechnology, and scientific ethics, PBL is highly relevant as it encourages students to examine issues from various perspectives and assess their social and scientific implications (Dewi, 2023). Additionally, the implementation of PBL has proven to enhance student motivation and active engagement. A longitudinal study by Yilmaz (2024) shows that the use of PBL over a semester not only impacts cognitive improvement but also affects affective aspects such as interest in learning, self-confidence, and academic resilience. This effect supports the sustainable development of critical thinking skills as students are more motivated to seek, evaluate, and synthesize information. This aligns with Saavedra's (2020) statement that 21st-century skills, especially in science, demand a learning approach that promotes critical, collaborative, and reflective thinking.Thus, the findings of this research reinforce the importance of integrating the Problem-Based Learning model in Biology education, particularly on topics that require higher-order thinking skills such as Biotechnology. PBL not only helps students understand concepts more deeply but also shapes the character of learners who are critical, adaptive, and responsible towards contemporary scientific issues. These findings have significant implications for teachers and curriculum developers to adopt this approach as a solution to the limitations of conventional learning, which tends to be passive and offers minimal stimulation for critical thinking.

4. CONCLUSION

Based on the results of the study which showed that the average value of critical thinking skills in the experimental group increased from 56.25 in the pretest to 80.75 in the posttest with a difference of 24.50 points, while the control group only increased from 55.88 to 68.13 with a difference of 12.25 points, it can be concluded that the Problem-Based Learning (PBL) model is more effective in improving critical thinking skills of grade XI MIPA students in Biotechnology material compared to conventional learning. Statistical analysis using the paired sample t-test showed a significant increase in both groups ($p < 0.05$), but the t-count value in the experimental group (14.32) was much higher than the control group (8.45), indicating a stronger PBL effect. In addition, the independent sample t-test strengthened this finding with a t-count value of 4.78 and a significance of 0.000, confirming a significant difference between the two groups in the posttest. The PBL model provides an active and contextual learning experience through collaborative real-world problem solving, which is highly relevant in complex and multidisciplinary biotechnology learning, thus effectively developing students' critical analysis, evaluation, and decision-making skills. Therefore, the application of PBL is highly recommended as a learning strategy to improve students' critical thinking skills at the high school level.

5. ACKNOWLEDGEMENT

It is recommended that further research be conducted to examine the extent to which the improvement in critical thinking skills obtained through the PBL model can be maintained over a certain period of time after learning, for example several months after the intervention.

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