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Problem-based learning: Improving critical thinking abilities, science literacy and students' independence in biology

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Abstract

This study is driven by the inadequate development of critical thinking, scientific literacy, and independent learning among biology students. To address these issues, the problem-based learning (PBL) model is considered necessary to enhance these skills. Problem-based learning facilitates the exploration of critical thinking, problem-solving, and real-life attitudes such as being active, independent, and cooperative. This research aimed to assess the effectiveness of the problem-based learning model in enhancing critical thinking skills, scientific literacy, and student independence in biology education. The study employed a quasi-experimental design with a non-randomized control group pretest-posttest. The sample comprised 56 students, with 27 in the experimental class (Class A) receiving problem-based learning and 29 in the control class (Class B) receiving conventional instruction. Critical thinking ability was measured using indicators such as problem formulation, argument analysis, deduction, induction, and decision-making. Scientific literacy was assessed through pretest and posttest evaluations, and student-independent learning was gauged using a questionnaire. The findings indicated a significant improvement in critical thinking skills as a result of using the PB model. In conclusion, the study demonstrates that students utilizing the PB model exhibit better critical thinking skills, scientific literacy, and independent learning compared to those using conventional methods.

Keywords: PBL; Critical Thinking; Scientific Literacy; Independent Learning

1. Introduction

In the era of globalization, it is necessary to have quality human resources who think critically and creatively solve problems, understand technology, and adapt to the changes and developments of the times [1]. Nichols In [2] argues that there are four education principles in the 21st century. Namely, teaching must be student-centered, education must be collaborative, learning must have context, and schools must be integrated with the community. For this reason, the educational process needs and arouse students' curiosity about something. An intense curiosity fuels a culture of learning, the courage to ask questions, and the desire to create. In this context, students must learn how to seek and construct knowledge, not just receive it from faculty. Similarly, knowledge should be seen as the learner's construction or transformation, not as something finished that needs to be transferred to the student. The teacher's position is as a facilitator and motivator, some of the skills needed to face future challenges are critical thinking, scientific mastery, and the ability to work independently. Critical thinking skills are planned and explicit processes used in mental activities such as skilled problem-solving decision-making and scientific research [3]. Critical thinking is used in mental activities such as problem-solving, decision-making, hypothesis analysis, and scientific research [4]. In addition, the skills that students must also have to meet the demands of life in various situations of the global era are scientific understanding. Scientific literacy is the ability to understand, communicate, and apply science skills to solve various problems [5].

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Scientific knowledge is directly related to forming a new generation with more substantial scientific intelligence, which can communicate research knowledge effectively to the public [6]. The culture of science is the primary key to facing the challenges of the 21st century to meet the needs of water and food, control disease, produce sufficient energy, and deal with climate change [7]. The low scientific literacy of Indonesian students is caused by several factors, including the curriculum and education system, the choice of teacher teaching methods and models, learning facilities and infrastructure, learning resources, teaching materials, and others. One of the factors that directly affect student learning activities and affect the low literacy skills of students is the selection of teacher learning methods and models [8].

The aspect of student academic success is also determined by the ability of students to regulate their existence (self-regulation) in solving the problems they face [9]. Suggests that people with high learning autonomy tend to be better learners, monitor, evaluate, and manage their learning effectively, save time completing assignments, manage study time effectively, and achieve high scores in science. In addition, according to [10], learning autonomy has advantages for students to support their activities at school and develop skills when entering the general world of work. Similarly, [11] argues that students with high independence develop high self-esteem. The phenomenon of the lack of critical thinking skills, scientific literacy, and independent learning is also experienced by students. One of the causes is the method, the learning model that has been applied by lecturers in the learning process is still using conventional methods. This method is more dominated by the teacher, while students listen more and take notes on what is explained by the teacher, as a result, students seek less information on their own, they tend to ask the teacher.

Lack of independence in learning causes students to have difficulty solving problems, thinking critically, and making decisions. Based on these learning problems, an appropriate learning model is needed to overcome these problems. One of the learning models that can improve critical thinking skills, scientific literacy ability, and independent learning is a problem-based learning model (PBL). PBL is a learning model that uses contextual problems that occur in the environment [12]. PBL can explore critical thinking skills problem-solving skills, and attitudes needed in real life such as being active, independent, and cooperative [13] and acquiring essential knowledge and concepts from the subject matter, training higher-order thinking including learning how to learn (metacognitive) [14], train students to become independent and self-regulating learners. Increasing learning independence will have an impact on high student learning outcomes. [9] said that one of the important sub-factors of individual circumstances that affect learning outcomes is learning independence. Based on these problems, the purpose of this study was to examine the use of problem-based learning models to improve critical thinking skills, scientific literacy, and student learning independence in biology learning.

Material and Methods

1.1. Study Design

This research is quasi-experimental using a nonrandomized control group pretest-posttest design. The research design is briefly presented in Table 1.

Table 1 Research Design Pretest-Posttest Control Group Design

Class	Pretest	Treatment	Post-test
Experiment	O1	X	O2
Control	O3	-	O4

Note:E= experimental class, C= control class, X= PBL learning model, O1 = experimental class pretest score; O2 = experimental class posttest score, O3= control class pretest score; O4= control class posttest score.

1.2. Participants, Settings, and Measures

The population in this study were third-semester students who programmed the animal structure course. The sample used was 56 students, 27 experimental class students (Class A) treated with PBL and 29 control class students (Class B) given conventional learning. Critical thinking ability data is measured using indicators of ability to formulate problems, provide and analyze arguments, deduction, induction, and make decisions. Assessment of critical thinking ability test results using an assessment rubric adapted from a scale of 0-4, then converted to an interval scale of 0-100 [15]. The scientific literacy ability test is structured in the form of multiple choice. The test is given in two stages, namely at the beginning (pretest) and at the end (posttest) of learning, with the characteristics of each question in each test being identical. Measurement of scientific literacy in this study was carried out using multiple-choice questions referring to the category of scientific literacy skills developed [16] adapted by [17] using seven indicators as follows in Table 2.

Table 2 Description of the Test of Scientific Literacy Skills (TOSLS)

1.	Identify valid scientific opinions.
2.	Carry out an effective literature search
3.	Understand the elements of research design and how they impact the findings/conclusions
4.	Create graphs precisely from the data
5.	Solve problems using quantitative skills, including basic statistics
6.	Understand and interpret basic statistics
7.	Perform inference, prediction, and drawing conclusions based on quantitative data.

Source: [17]

A questionnaire was used to determine students' learning independence towards their ability to take the necessary actions to solve problems related to scientific literacy skills during the learning process. The questionnaire scale used refers to the Likert attitude scale model (1-4).

1.3. Data analysis

The data that has been collected includes data on critical thinking skills, scientific literacy, and learning independence that has been obtained through the pretest and posttest were analyzed using statistical analysis of Covariance Analysis (ANCOVA) and followed by the Bonferroni difference test. Before the analysis, the prerequisite tests were carried out, namely the normality test and the homogeneity test of variance. The normality test used the One-Sample Kolmogorov-Smirnov test, and the homogeneity test of variance used Levene's Test of Equality of Error Variances. Data analysis using SPSS 20.0 for Windows computer program application.

2. Result

2.1. Critical Thinking

The results of Ancova's statistical analysis calculation using the Problem-Based Learning Model on students' critical thinking variables are briefly presented in Table 1.

Table 3 Results of ANCOVA Test Using PBL on Biology Students' Critical Thinking

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1083.724a	2	541.862	54.824	0.000
Intercept	4639.685	1	4639.685	469.434	0.000
Critical Thinking	139.343	1	139.343	14.098	0.000
class	1030.639	1	1030.639	104.278	0.000
Error	52.830	53	9.884		
Total	347479000	56			
Corrected Total	1607.554	55			
R Squared = 0.674 (Adjusted R Squared = 0.662)					

Table 4 Further test results using Bonferroni

(I) Class	(J) Class	Mean Difference (IJ)	Std. Error	Sig. b	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Conventional	PBL	-8.675*	0.849	0.000	-10.37	-6.97
PBL	Conventional	8.675*	0.849	0.000	6.97	10.37
Based on estimated marginal means						
*. The mean difference is significant at the 0.05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

Based on Table 1 on the PBL class learning variable, the Fount value is 104.427 with a significance value of 0.000 (p <0.05). Thus the use of PBL in learning affects increasing students' critical thinking. The results of the Pairwise Comparison test using Bonferroni can be seen in Table 2. The results showed that the average critical thinking score of students taught using the PBL learning model was 82.77. Meanwhile, the average critical thinking score of students taught using conventional learning models is 74.09. The results of the Bonferroni test showed that the PBL learning group and the conventional learning group had a probability value of sig. 0.00 is smaller than 0.05 (p<0.05), so it can be concluded that the two lessons have a significant difference in effectiveness in improving students' critical thinking skills. The adjusted R-square value was obtained at 0.662 (66.2%). The result shows that the ability of the PBL learning model variable in this study affects the critical thinking ability variable by 66.2%, while the remaining 33.8%.

2.2. Student Science Literacy Ability

The results of the calculation of Ancova's statistical analysis of students' literacy ability variables can be briefly seen in Table 5. In the table, it is evident that the PBL class learning variable yielded an F value of 135.185 with a significance value of 0.00 (p<0.05). Therefore, the utilization of PBL in learning enhances students' science literacy skills. The outcomes of the Pairwise Comparison test utilizing Bonferroni are displayed in Table 6.

Table 5 The results of the ANCOVA Test of the Use of PBL on the Science Literacy Ability of Biology Students

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	74.135a	2	37.067	75.331	0.000
Intercept	92.742	1	92.742	188.477	0.000
Scientific literacy ability	8.999	1	8.999	18.287	0.000
class	66.520	1	66.520	135.185	0.000
Error	26.079	53	0.492		
Total	2706.000	56			
Corrected Total	100.214	55			
a. R Squared = 0.740 (Adjusted R Squared = 0.730)					

The results showed that the average literacy score of students taught using the PBL learning model was 7.87. Meanwhile, the average score of students' scientific literacy skills taught using conventional learning models is 5.69. The results of the Bonferroni test showed that the PBL learning group and the conventional learning group had a probability value of sig. 0.00 is smaller than 0.05 (p<0.05), so it can be concluded that the two lessons have a significant difference in effectiveness in improving students' scientific literacy skills. The adjusted R-square value was obtained at 0.730 (73%). The result shows that the ability of the PBL learning model variable in this study affects the student's scientific literacy ability variable by 73%, while the remaining 27%.

Table 6 Further test results using Bonferroni

(I) Class	(J) Class	Mean Difference (IJ)	Std. Error	Sig. b	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Conventional	PBL	-2.182*	0.188	0.000	-2.56	-1.80
PBL	Conventional	2.182*	0.188	0.000	1.81	2.56
Based on estimated marginal means						
*. The mean difference is significant at the 0.05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

2.3. Student Learning Independence

The results of the calculation of the ANCOVA statistical analysis of the learning independence variable are briefly presented in Table 7. These results indicate that the calculated F obtained is 9.546 with a significance value of 0.00 ($p < 0.05$). Thus, the use of PBL in learning can significantly improve students' scientific literacy skills. Furthermore, the results of the Pairwise Comparison test using Bonferroni can be seen in Table 8.

Table 7 The results of the ANCOVA Test of the Use of PBL on the Independent Learning of Biology Students

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1539.456a	2	769.728	15.898	0.000
Intercept	528.412	1	528.412	10.914	0.002
Independent learning	1379.179	1	1379.179	28.485	0.000
class	462.199	1	462.199	9.546	0.003
Error	2566.098	53	48.417		
Total	271965000	56			
Corrected Total	4105.554	55			
R Squared = 0.375 (Adjusted R Squared = 0.351)					

Table 8 Further test results using Bonferroni

(I) Class	(J) Class	Mean Difference (IJ)	Std. Error	Sig. b	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Conventional	PBL	-5.936*	1.921	0.003	-9.789	-2.083
PBL	Conventional	5.936*	1.921	0.003	2.083	9.789
Based on estimated marginal means						
*. The mean difference is significant at the 0.05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

Based on the results of further tests, it can be seen that the average student learning independence in the PBL class is 72.023, while the average student learning independence who is taught using the conventional learning model is 66.087. The results of the Bonferroni test showed that the PBL learning group with the conventional group had a probability value of sig. 0.00 is smaller than 0.05 ($p<0.05$), so it can be concluded that the two studies have a significant difference in effectiveness in increasing student learning independence. The adjusted R-square value was obtained at 0.351 (35.1%). The result indicates that the ability of the PBL learning model variable in this study affects the student's independent learning ability variable by 31.5%.

3. Discussion

Based on the overall research results, the critical thinking of students who received biology learning (animal structure material) using the PBL model was better (Mean = 82.77) compared to students who received conventional learning (Mean = 74.33). ANCOVA test results Fount value is 104.427 with a significance value of 0.000 ($p<0.05$), and the adjusted R-square value is 0.662 (66.2%). Thus the use of PBL in learning has a significant effect on increasing students' critical thinking, and the PBL variable can affect the critical thinking ability variable by 66.2%. The increase in critical thinking variables is due to learning that using PBL can encourage students to construct and connect their knowledge with its application in everyday life. In addition, with PBL, students can analyze and understand the meaning of the theory learned and acquire valuable skills for their lives in the community. In this study, students taught using the PBL model could formulate problems, provide arguments and analyze them, do deduction, induction, and make decisions. The results of other studies show that the use of PBL can positively impact students' awareness of creative thinking and decision-making abilities and improve students' critical thinking skills [18] [19]. In addition, this research is strengthened by the findings of research conducted by [20] proving that PBL can improve learning progress and student satisfaction. [21] also observed that students who were given the intervention using the PBL strategy performed better in higher-order thinking than the control group. In addition, some researchers also found that the structure and process of learning with the PBL model can improve students' critical thinking and prepare them to meet the initial competencies of practice [10].

The results showed that the PBL learning model affected students' scientific literacy skills with an average score of students' literacy skills taught by the PBL learning model 7.87 and an average score of students' scientific literacy skills taught using conventional learning models 5.69. The adjusted R-square value is 73%, indicating that the PBL learning model can affect students' scientific literacy skills by 73%. Based on the research results, students who are taught using the PBL model have a better ability to identify problems, explain phenomena scientifically, and make conclusions based on existing data compared to students who are given conventional learning. The PBL model is designed using a scientific approach, prioritizing independent learning and students' thinking skills. These results are in line with the research [22] argued that fact-oriented problems and placing problems as the starting point of learning are factors that can improve scientific literacy skills. The results of other studies also conclude that PBL can be used to build students' scientific literacy in terms of content and science competence.

Table 5 shows that PBL affects student learning independence ($p<0.05$). This evidence explains that students taught using the PBL model have better-learning independence than students who are taught conventionally. Students who are given PBL learning are more active in expressing their opinions and ideas, have self-confidence, and can work together with their groups. Students who were initially not very active seemed enthusiastic in solving the problems given. The results of this study are strengthened by previous research that the PBL learning model, compared to conventional methods, can increase students' independence in learning materials and understanding concepts.

4. Conclusion

The use of PBL has been proven to have a significant effect on increasing critical thinking, scientific literacy, and student learning independence in learning biology. PBL can affect critical thinking skills by 66.2%, students' scientific literacy skills by 73%, and learning independence by 31.5%. Thus the PBL model can be used as a solution to improve critical thinking skills, scientific literacy, and student learning independence in biology learning.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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