RESEARCH ARTICLE

The impact of problem-based learning and metacognition on solving environmental pollution issues

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Abstract: The lecture technique still dominates in biology education, and there are not enough hands-on, interactive, creative, and problem-solving learning activities to encourage students to apply their problem-solving skills. The purpose of this study is to examine how the problem-based learning (PBL) model and students' metacognition skills affect their ability to solve environmental pollution issues. A total of 60 X MIPA students from SMA Muhammadiyah 16 Jakarta comprised the total sample of the research, collected using the quasi-experimental approach. For the study, two groups were utilized: the experimental group (X MIPA 1) and the control group (X MIPA 2). A 2 x 2 factorial design with a pretest-posttest control group was employed for the investigation. The instruments used in the study were classified as tests or non-tests. The test instrument is an essay designed to collect data on problem-solving ability and metacognition ability, while the non-test instruments are student worksheets that refer to the PBL stage, and the observation sheet is designed for instructors and students. Data analysis using ANCOVA with a significance level of 0.000 < α = 0.05 indicates that H0 was rejected. The interaction between the PBL learning model and students' metacognition skills also has an impact on their capacity to address environmental pollution-related issues.

Keywords: metacognitive ability, environmental pollution, problem-based learning, problem solving ability

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Introduction

Challenges to learning in the 21st century are highly global in nature. Students need open-mindedness, effective communication and collaboration in groups, and problem-solving skills to remain competitive in the future (Liebech-Lien & Sjølie, 2021; Scott, 2015; Wang et al., 2022). Students who utilize problem-based learning (PBL) models demonstrate superior problem-solving abilities compared to those engaged in conventional learning methods (Damopolii et al., 2018; Kök & Duman, 2023; Sari et al., 2021). Problem-solving skills yield positive and significant results in students' academic achievements when viewed from a metacognitive perspective (Dindar et al., 2020; Zhao et al., 2019).

Currently, in Indonesia, the teaching of science continues to heavily rely on the lecture method, with less emphasis placed on active learning, collaboration, creativity, and problem-solving (Fauzi, 2019). Consequently, participants do not fully utilize their problem-solving abilities (Koswara et al., 2019). One example within the realm of biology education is the ability to address issues such as environmental pollution caused by the spread of viruses, ecosystem survival, and evolutionary phenomena. Biology teachers typically focus solely on textbook resources when providing instruction, even though the subject matter necessitates reasoning and problem-solving abilities (Ramdiah et al., 2019). This suggests that biology teachers may not be familiar with teaching methods that can help develop students' problem-solving skills.

The selection of a relevant and applicable learning model is crucial to support the learning process. One model that can be explored for evaluating participants' problem-solving abilities in education is the problem-based learning (PBL) model (Argaw et al., 2017). This particular learning model is believed to motivate participants to seek solutions to biology-related problems either independently or in groups. The adoption of the PBL model in the learning process has the potential to cultivate participants' scientific thinking abilities (Birgili, 2015; Wulandari & Shofiyah, 2018), as they are encouraged to observe problems, ask questions, generate hypotheses, seek answers, and present their findings (Wilder, 2015; Yew & Goh, 2016). The implementation of this model should also be reviewed with respect to metacognition, which refers to the ability to learn and think and is employed to regulate and control cognitive processes for more effective learning outcomes (Hogan et al., 2015; Saputri & Kesumawardani, 2021).

PBL also has the potential to improve students' metacognition (Aliyu et al., 2016; E. J. Choi, 2016). Metacognition is the process by which individuals become conscious of their own thinking and utilize internal strategies to arrive at solutions that extend beyond their current knowledge or experiences. Furthermore, metacognition aids in identifying knowledge gaps and conceptual difficulties, prompting individuals to seek optimal approaches to problem-solving (Dye & Stanton, 2017). Additionally, metacognition plays a crucial role in future learning. Supported by the assertion that metacognition is critical in constructing explanations, fostering metacognitive skills entails practicing problem-solving abilities to gain a deeper understanding of biological concepts (Istiana & Awaludin, 2018).

Research analyzing the influence of PBL on biology learning has often been carried out, although research that focuses on environmental material is still limited. Several previous studies have highlighted the positive impact of PBL on students' environmental attitude (Amin et al., 2020) and environmental literacy (Febriasari & Supriatna, 2017). On the other hand, the literature also shows that students' metacognitive skills play an important role in the learning process (Teng, 2023; van Velzen, 2016), including in dealing with environmental issues. However, research that specifically explores the interaction between PBL and metacognitive skills in the context of environmental pollution problem solving is still difficult to find. Therefore, the aim of this research is to analyze the influence of PBL and metacognition on students' ability to solve environmental pollution problems.

Method

This research is quantitative research with quasi methods. The experiment used two groups, namely experimental (PBL) and control (Discovery Learning/DL). The research consists of three variables, namely X1 (PBL), X2 (metacognition ability), and Y (problem-solving ability). The research design used is a 2 x 2 factorial design pretest posttest control group design. Use of pretest to find out students' initial problem-solving abilities, then the use of posttest is used to determine the problem-solving ability of students after implementing PBL. The research time began in the year of teaching 2021/2022. Use pretest ability to solve problems as the baseline for participants' education, then use posttest to assess the ability to solve problems of participants' education after PBL is applied. Pretest and posttest will be given to each subject studied at the same time with the same instrument, both in the experimental class and the control class.

The metacognition ability of the participants' education will also be reviewed and grouped into tall or low categories. The grouping of metacognitive ability of participants' education starts with sorting the scores obtained by participants' education from the highest to the lowest. Once sorted, they are divided into the top 27% group (which has the highest scores) and the bottom 27% group (which has the lowest scores). For further explanation, the study design is stated in Table 1.

Table 1. Research design

Metacognition Ability(B)	**Model Learning (A)**	
	PBL (Experiment)(A_1)	***Discovery Learning* (Control) (A_2)**
Height (B_1)	A_1B_1	A_2B_1
Low (B_2)	A_1B_2	A_2B_2

Description

A_1B_1 : Ability solving problem participant educate on the PBL model with ability metacognition high (27% group above).

A_1B_2 : Ability solving problem participant educate on the PBL model with ability metacognition low (27% group bottom).

A_2B_1 : Ability solving problem participant students on the Discovery Learning model with ability metacognition high (27% group above).

A_2B_2 : Ability solving problem participant students on the Discovery Learning model with ability metacognition low (27% group bottom).

The population for the study is class X MIPA SMA Muhammadiyah 16, Central Jakarta City, Special

Region Capital Jakarta. The sample selection was conducted through Simple Random Sampling, and 70 respondents were chosen. Out of these, 60 participants were selected as samples based on the Slovin formula. The schools were randomly assigned to the treatment group.
The learning process is carried out in class experiments using the PBL model and in class controls using the traditional learning model used by biology teachers in schools, namely Discovery Learning. The learning process was carried out in each class three times in accordance with the lesson plan. In the research, data analysis techniques are used. This was done with the Analysis of Covariances (ANCOVA) method of testing hypotheses. This was done with $\alpha = 0.05$ using SPSS version 25 as a precondition for testing hypotheses on statistical inference. Then, normality, homogeneity, linearity, interaction, and autocorrelation tests were done first.

Results and Discussion

This section covers four aspects: identifying problems, defining goals, exploring strategies, and implementing strategies to support successful learning. The Table 2 shows the average value per aspect of problem-solving abilities of students in the control class.

Table 2. The average value of each aspect of a student's ability to solve a problem

No.	Aspect Ability Solving Problem	Average	Information
1	Identify problem	85.44	Very Good
2	Determine objective	79.69	Good
3	Explore strategy	79	Good
4	Implement strategy for support success learning	84.38	Good

The problem-solving abilities of the students studied in this study include four aspects, namely identifying problems, determining goals, exploring strategies, and implementing strategies to support successful learning. Based on the results of the average value of each aspect of students' problem-solving abilities, it is known that the class with the PBL model (A1) is superior to the DL model (A2), as can be seen in Figure 1.

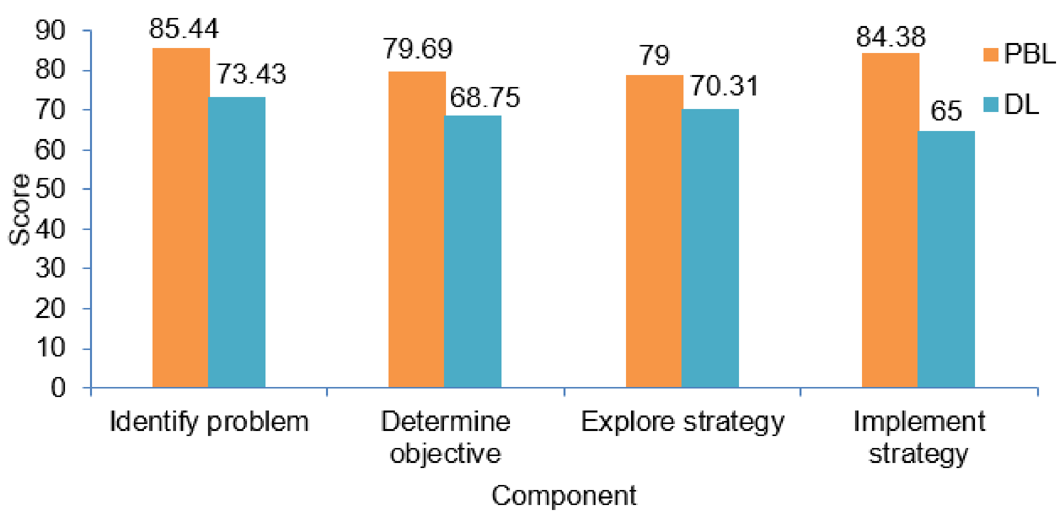

Figure 1. Student Problem Solving Ability with PBL (A_1) and DL (A_2) models

The results of the research shown in Figure 1 show that the problem-solving ability of students who use the PBL model obtains a higher score with an average of 78.47 compared to students who use the DL model with an average of 65.86. The high problem-solving ability in the PBL model is suspected because students get meaningful learning directly, as the problems they encounter come from their daily lives. This is in line with the opinions of experts who state that when implementing PBL, the problems presented must be complex and occur in the real world in order to explore students' problem-solving abilities.
Based on the results of the average value of each aspect of students' problem-solving abilities in terms

of high and low metacognitive abilities, it is known that students' problem-solving abilities with high metacognitive abilities (B1) are superior to those with low metacognitive abilities (B2), as can be seen in Table 3.

The results of the average value of each aspect of problem-solving abilities in Table 4 state that students have the greatest average in the aspect of determining goals, in terms of high metacognition ability of 87.50 and low of 71.88. Based on these results, the ability of metacognition affects one aspect of determining goals to improve the quality of learning that has been implemented. Several studies have shown that the aspect of determining goals is primarily to increase students' self-awareness and understanding of how they learn and think so that they can become more effective and independent learners.

Table 3. Students' problem-solving abilities in terms of high metacognitive abilities (B1) are superior to low metacognitive abilities (B2)

No.	Aspect Ability Solving Problem	Average	
		High metacognitive abilities (B1)	Low metacognitive abilities (B2)
1	Identify problem	82,21	68,75
2	Determine objective	87,50	71,88
3	Explore strategy	78,12	67,18
4	Implement strategy	85,93	65,63

The average problem-solving ability of group A1B1 > A2B1 > A1B2 > A2B2. Based on the results of the average value of each aspect of students' problem-solving abilities in all groups A_1B_1, $A2B_1$, A1B2, and A2B2 can be seen in Figure 2.

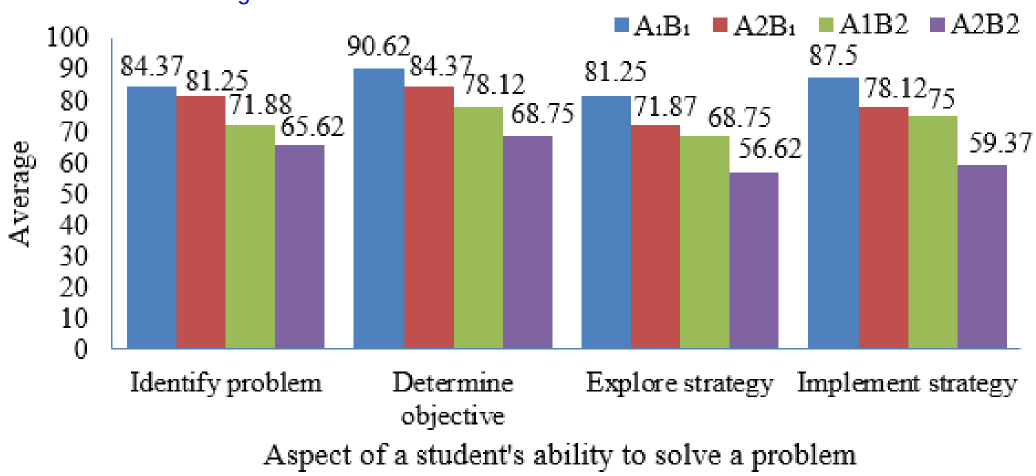

Figure 2. The average problem-solving ability of the group (A1B1, A1B2, A2B1, A2B2)

Based on the average problem-solving ability score, the highest group A1B1 and the lowest group A2B2 in Figure 2 have an average difference of 37.61. This difference proves that learning through the application of the PBL model in terms of high metacognitive abilities makes students trained to solve a given problem, as well as the ability to organize, supervise, and evaluate their own learning process. Based on several studies explaining that students have good problem-solving skills to deal with various problems in the real world, appropriate solutions are needed by identifying learning objectives, selecting relevant learning resources, evaluating their learning progress, and adjusting their learning strategies to achieve learning goals.

Before analyzing the data, normality, homogeneity, linearity, and interaction tests must be performed, which were previously referred to as precondition data analysis. The Kolmogorov-Smirnov test was used to determine the normality of the data. To determine whether the data studied is normally distributed or not. Ability problem-solving participant educate class experiment and class control to class capable metacognition high and low each have mark (sig.) > $\alpha = 0.05$, so that their own normal data distribution. Table 4 displays the results of the normality test.

Table 4. Normality test results whole group

group	*(sig)*	Results	Information
A_1B_1	0.45	0.45 > 0.05	Normal Distribution
A_1B_2	0.34	0.34 > 0.05	Normal Distribution
A_2B_1	0.24	0.24 > 0.05	Normal Distribution
A_2B_2	0.13	0.13 > 0.05	Normal Distribution

Levene statistics were used to test homogeneity in order to determine whether the studied data is distributed in a homogeneous manner. The significance value obtained for the homogeneity test was 0.19, which is greater than the significance level (α = 0.05). This indicates that the samples from the data are homogeneous or originate from the same population. Table 5 displays the results of the homogeneity test.

Table 5. Homogeneity test results whole group

Data	Sig.	Results	Information
Experiment Control	0.20	0.19 > 0.05	The variance is homogenic

The linearity test was used to determine whether there is a linear relationship between two or more variables in a significant manner. The results of the linearity test revealed a significant effect on deviation, as the linearity value (0.09) was greater than the significance level (α = 0.05). This indicates a significant linear relationship between the Ability Solving Problems with PBL Models and Capabilities Metacognition. Therefore, these test results can be utilized for the ANCOVA test. It is important for the prerequisite test to ensure that the analysis of the slope of the regression line between groups is the same. The similarity in the slope of the line indicates that the ability to solve problems differs between classes implementing the PBL and DL models, as reviewed from groups with high and low metacognition in each model treatment. The results of the interaction test are presented in Figure 3.

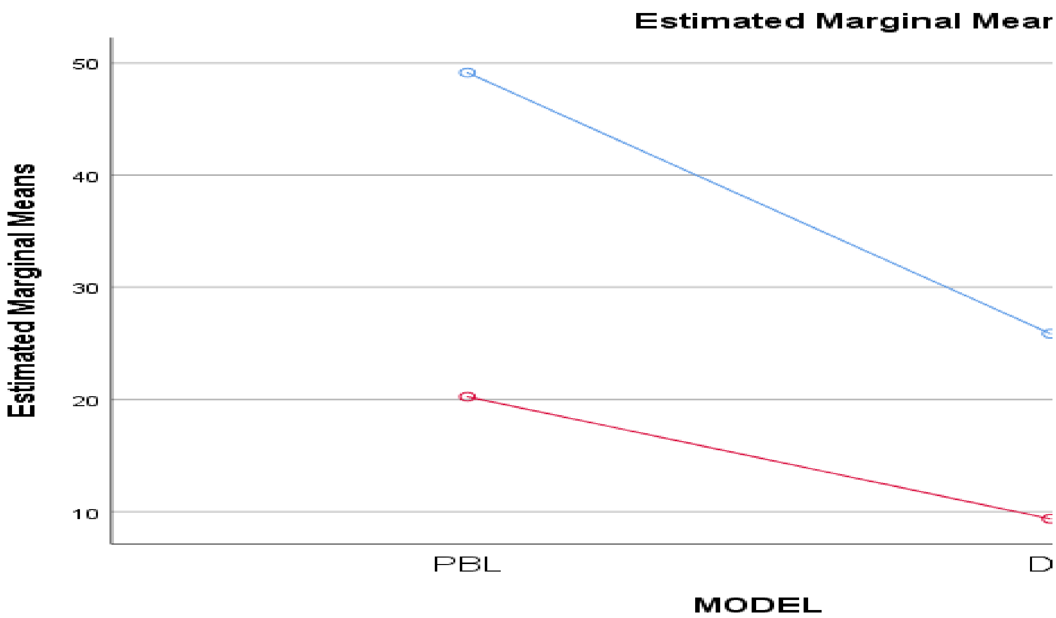

Figure 3. Interaction test results between PBL and DL models

Autocorrelation testing was used. In linear regression, there is a significant correlation between faults confounding (residuals) on two or more variables. The results of autocorrelation testing show sig. on Durbin-Watson of 0.75 > α = 0.05, indicating a significant correlation between member sorted observations based on time or room in a manner significant between ability solving problem with PBL models and capabilities metacognition. After determining that the research data meet the prerequisite test analysis, hypothesis testing can be continued with the ANCOVA Test. Table 6 shows how to test the ability data hypothesis solving problem with PBL and DL models based on ability metacognition participant educate.

Table 6. ANCOVA test results

Data Type	Amount Square Type III	df	Squared Average	F	Sig.
All variable	6446.813[a]	2	3223,406	92,792	.000
Ability Metacognition	4117,781	1	4117,781	118,538	.000
Learning Models	2329031	1	2329031	67,045	.000
Error	1007,406	29	34,738		
Total	29684000	32			

The significance of the number in all data variables can be used to determine the influence of learning models and metacognitive abilities on participants' problem-solving abilities. It was discovered that the significance value obtained for the n value was 0.000 < (sig.) α = 0.05, indicating that learning models and metacognitive abilities have an influence on participants' problem-solving abilities.

PBL stages can educate participants on how to analyze situations, apply knowledge, distinguish between facts and opinions, and create tasks in an objective, methodical, and universal manner. Situational problems are presented to participants in the same way they occur in the real world, primarily actual, real problems in society and the environment. The PBL model implements real-world problems as a context for participants to learn how to think critically and develop problem-solving skills. This stage aims to educate participants on how to take initiative and use critical thinking to solve problems (Slavin, 2008). The application of this model's stages felt sufficient for improving the learning process carried out during this study because the PBL model can challenge participants to think deeply and develop problem-solving abilities (Argaw et al., 2017; E. Choi et al., 2014). The PBL model offers multiple advantages such as enhancing lesson comprehension, challenging participants to acquire new knowledge, and fostering problem-solving skills relevant to societal challenges (Dolmans et al., 2016; Yew & Goh, 2016). Based on the results of the analysis in this study, the data group using the PBL learning model with high metacognitive ability performed better than the group using the DL learning model with low metacognitive ability. Participants who use the PBL learning model with high metacognitive ability have better problem-solving abilities than participants with low metacognition. In line with this finding, ability metacognition is capable of optimizing the level of ability participants have in problem solving or achieving optimal learning outcomes (Hargrove & Nietfeld, 2015; Zhao et al., 2019). Metacognitive ability equips participants for future education. This is supported by the statement that metacognition plays an important role in explaining concepts. Practicing metacognition means practicing the ability to solve potential problems, which helps in understanding biology concepts. Participants are educated on how to constantly monitor, control, and evaluate their problem-solving abilities through the development of metacognitive awareness (Dye & Stanton, 2017).

Furthermore, the findings show that problem-solving abilities can be attributed to the application of metacognitive abilities in formulating specific methods or techniques for finding solutions. Other research also suggests that metacognitive ability can be used to raise awareness of one's own cognitive activity in problem solving, regulate cognitive processes, and master the strategies for directing, planning, and monitoring cognitive activity. Students with strong metacognitive abilities are better equipped to face and solve complex problems (Güner & Erbay, 2021). High metacognitive abilities can have a positive effect on problem-solving abilities because through this ability (Tachie, 2019), students can reflect on their own thinking processes and make improvements to these thinking processes.

On the other hand, PBL stages can educate student on how to analyze situations, apply knowledge, distinguish between facts and opinions, and create tasks in an objective, methodical, and universal manner (Argaw et al., 2017; E. Choi et al., 2014). Situational problems are presented to participants in the same way that they occur in the real world, primarily actual, real problems in society and the environment (Tan, 2003). The PBL model implements real-world problems as a context for participants to learn how to think critically and develop problem-solving skills. Stage This aims to educate participants on how to take initiative and use critical thinking to solve problems (Slavin, 2008). This model's application stages felt sufficient for improving the learning process carried out during this because the PBL model can confront participants and teach them to one problem so that participants can develop high thinking ability and ability to solve problems as well as obtain new knowledge related to the problem. This study shows the high value of students' problem-solving abilities in groups that study with the PBL learning model, and high metacognitive abilities indicate that educators are able to design active and interesting learning for students. The interaction between good learning models from educators and metacognitive abilities will help students achieve optimal problem-solving skills.

Conclusion

In conclusion, according to the findings of the study, there is an influence of interaction learning models such as PBL and metacognitive abilities on the participants' ability to solve pollution problems in the environment. The research findings suggest that students' problem-solving and metacognition skills are highly valued in PBL learning groups, which implies that teachers can create engaging and dynamic lessons for their students. When a good teaching model is combined with metacognitive skills, students will develop their best problem-solving abilities. Students' problem-solving abilities are directly related to their metacognitive abilities.

Based on the findings of the study, recommendations include that social studies teachers should utilize both the demonstration method (preferably) and storytelling when teaching social studies to pupils with intellectual disabilities. In addition, teachers of pupils with intellectual disabilities should have opportunities for in-service training, workshops, seminars, and conferences to update their knowledge on the appropriate use of demonstration methods and storytelling in social studies classrooms.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

A. Cahyadini: writing original article, collecting data and review, and revision; **H. Isfaeni:** methodology, review and revision; and **R. Komala:** conducting the research, collecting data, writing original article, and revision.

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