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The Effect of the Problem-Based Learning (PBL) Instructional Model on the Cognitive Learning Outcomes of Grade X Students at MA Miftahul Ulum Bettet on the Topic of Environmental Pollution

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Abstract: This study aimed to analyze the effect of the Problem-Based Learning (PBL) model on students' cognitive learning outcomes on the topic of environmental pollution in Grade X at MA Miftahul Ulum Bettet, Pamekasan. The study used a quantitative approach with a quasi-experimental, nonequivalent pretest–posttest control-group design. The sample consisted of two classes: X IPA C, the experimental class receiving PBL, and X IPA B, the control class receiving conventional instruction (lecture and discussion), totaling 47 students. Cognitive learning outcomes data were collected using a 9-item essay test measuring cognitive domains C1–C5, administered as both a pretest and posttest. Data were analyzed using the nonparametric Kruskal–Wallis test because the normality assumption was not met. The results showed a significant difference between the cognitive learning outcomes of students in the experimental and control classes, with posttest means of M = 66.8 (SD = 5.24) and M = 53.2 (SD = 4.81), respectively, and $\chi^2(1) = 32.7$; $p < 0.001$; $\varepsilon^2 = 0.711$, indicating a large effect. These findings indicate that implementing PBL is effective in improving students' cognitive learning outcomes in environmental pollution material and underscore its relevance as an alternative instructional model for developing critical thinking and problem-solving skills in Biology learning at the madrasah aliyah level.

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Introduction

Twenty-first-century education requires integrating literacy competencies, mastery of science and technology, higher-order thinking skills, and adaptive character in response to global change. Learners are no longer merely recipients of information; rather, they are active agents who construct knowledge through interaction and the resolution of authentic problems, while teachers serve as facilitators who design meaningful learning experiences (Redhana, 2019; Scundy, 2019). In this context, the ability to make sound decisions and solve problems becomes an essential cognitive requirement, particularly in science learning that is rich in contextual issues such as environmental pollution. The Problem-Based Learning (PBL) model is considered relevant to these demands because it uses real-world problems as the starting point of learning, encourages students to think critically and not stop at the first solution that emerges, and provides broad opportunities for students to express ideas and communicate scientifically (Oktaviana, 2020). Therefore, in theory, PBL has the potential to improve cognitive learning outcomes while also fostering twenty-first-century skills.

However, empirical evidence from the field suggests that this potential has not been fully realized. Observations and interviews with the Biology teacher at MA Miftahul Ulum Bettet indicate that students' cognitive learning outcomes on environmental pollution and environmental change topics remain low. Daily test data show that in Grade X IPA B, 50% of 36 students had not yet achieved the minimum mastery criterion (KKM) of 72 and were therefore categorized as not meeting mastery. This indication suggests that the instructional strategies used have not optimally facilitated students' cognitive engagement at the expected level, especially in understanding abstract and complex concepts related to ecosystems and environmental pollution. One pedagogical approach expected to address this problem is the systematic implementation of PBL in the context of environmental pollution materials at the madrasah aliyah level. Previous research indicates that PBL can improve students' cognitive learning outcomes (Pratiwi, 2019). Still, its effectiveness needs to be examined more specifically across different curricular contexts, levels, and institutional characteristics, including faith-based schools such as MA Miftahul Ulum Bettet.

A growing body of recent studies consistently reports that PBL has a positive effect on cognitive learning outcomes across educational levels and subject areas. At the primary-school level, PBL has been shown to improve cognitive outcomes in IPAS (Ulya & Pritasari, 2025; Afandi, Subekti, & Saputro, 2024) as well as in science learning through various innovative approaches, including STEAM integration (Astuti et al., 2023) and Ethno-PBL that incorporates ethnoscience contexts (Handayani, 2023). At the secondary level, PBL has been reported to be effective in improving problem-solving ability and cognitive learning outcomes in Biology (Utami, Fitriani, & Efendi, 2023), cognitive and psychomotor aspects of Biology (Darmayanti et al., 2022), and learning outcomes on animal life cycle topics (Irmayanti et al., 2025) and Grade X Biology (Arumsari et al., 2023). Similar findings have also been reported in Physics (Suindhia, 2023), IPAS in general (Afandi et al., 2024), and even in Accounting at vocational schools (Rahmadhani et al., 2022), collectively strengthening the empirical evidence that PBL can enhance cognitive achievement across disciplines. Nonetheless, this literature remains dominated by general primary and secondary school contexts with diverse topic foci, and relatively few studies specifically evaluate the effect of PBL on the cognitive learning outcomes of Grade X madrasah aliyah students on environmental pollution material. Therefore, this study was designed to address this gap by providing more targeted empirical evidence on Biology learning in madrasah aliyah, thereby enriching the theory and practice of PBL-based science learning and offering more relevant and applicable pedagogical recommendations for teachers in madrasah aliyah settings.

Research Method

Research Design and Procedure

This study employed a quantitative, quasi-experimental design of the nonequivalent pretest–posttest control-group type (Sugiyono, 2010) to examine the effect of implementing the Problem-Based Learning (PBL) model on students' cognitive learning outcomes in Biology on the topic of environmental pollution at MA Miftahul Ulum Bettet, Pamekasan. Two classes were used as the experimental and control groups; both were administered a pretest to measure initial ability. The experimental group received PBL instruction (X_1), whereas the control group received conventional instruction in the form of lectures and discussion (X_0). At the end of the treatment, both groups were given a posttest (O_2 and O_4) to assess cognitive learning outcomes (Table 1). The study was conducted in the even semester of the 2021/2022 academic year over six meetings, including the pretest, implementation of learning according to the lesson plan (RPP) for each model, and the posttest in both groups.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O1	X1 (PBL)	O2
Control	O3	X0 (Lecture–discussion)	O4

Participants, Variables, and Research Instruments

The study population comprised all female Grade X students at MA Miftahul Ulum Bettet, Pamekasan. At the same time, the sample was selected purposively, with Grade X IPA B (female) as the control group and Grade X IPA C (female) as the experimental group, in the even semester of the 2021/2022 academic year. The independent variable was the PBL learning model, whereas the dependent variable was students' cognitive learning outcomes, i.e., cognitive achievement influenced by the instructional treatment. The treatment instruments consisted of learning tools, including the syllabus, lesson plans (RPP), and student worksheets (LKS) developed according to the PBL syntax and conventional instruction. To ensure the intervention's implementation fidelity, an observation sheet for lesson-plan implementation was used and completed by an observer during the learning process. The measurement instrument was a cognitive learning outcomes test comprising 9 essay items, developed based on cognitive indicators C1–C5, and administered as both the pretest and posttest in the experimental and control groups (Arikunto, 2013).

Data Collection and Analysis Techniques

Data collection was carried out in two stages: preparation and implementation. In the preparation stage, the researcher conducted preliminary observations, obtained permission from the school, developed and validated learning tools (syllabus, RPP, and LKS), constructed test items with answer keys and scoring rubrics, and prepared an observation sheet to assess the implementation of the PBL syntax. In the implementation stage, the researcher administered a pretest to measure students' initial cognitive ability, implemented instruction according to the assigned model in each class (PBL in the experimental class and lecture–discussion in the control class), observed learning implementation, and administered a posttest to measure cognitive learning outcomes after the treatment. Quantitative data were analyzed in Jamovi 2.0 using a sequence of assumption tests and hypothesis tests. Assumption tests included normality testing using the Shapiro–Wilk test at the 0.05 significance level, supported by the Liliefors test, as well as tests of variance homogeneity (Sugiyono, 2010; Riduwan, 2015) and other prerequisite checks relevant to quasi-experimental designs. After the assumptions were examined, hypothesis testing was planned using analysis of covariance by controlling the pretest score as a covariate, with decisions based on the p-value (sig); a sig value < 0.05 was interpreted as indicating a significant effect of the PBL model on students' cognitive learning outcomes compared with conventional instruction.

Result and Discussion

Description of Cognitive Learning Outcomes Data

The learning outcome data analyzed in this study comprised posttest scores on cognitive learning outcomes related to environmental pollution. The mean, standard deviation, and minimum and maximum scores for the experimental and control classes are presented in Table 2. The experimental class (N = 24) obtained a mean posttest score of M = 66.8 with a standard deviation of SD = 5.24 and a score range of 56–72. Meanwhile, the control class (N = 23) had a mean posttest score of M = 53.2, SD = 4.81, and a score range of 44–62. This mean difference indicates that students who learned through the Problem-Based Learning (PBL) model achieved higher cognitive learning outcomes than those who received conventional instruction (lectures and discussion). Considering that both groups were previously given a pretest to capture initial ability on ecosystem and environmental pollution material, the posttest score difference suggests an effect of the instructional treatment on students' final cognitive achievement.

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Table 2. Mean Scores of Cognitive Learning Outcomes

Descriptives	Class	Posttest
N	Experimental	24
	Control	23
Mean	Experimental	66.8
	Control	53.2
Standard deviation	Experimental	5.24
	Control	4.81
Minimum	Experimental	56
	Control	44
Maximum	Experimental	72
	Control	62

Assumption Test Results

Before testing the hypothesis, several statistical assumptions relevant to the research design were examined. The covariate homogeneity test (Table 3) yielded F = 1.21 with p = 0.278 (> 0.05), indicating that there was no difference in covariate variance between the experimental and control classes; thus, the covariate homogeneity assumption was met. However, inspection of the regression slopes between the covariate and the dependent variable (Figure 1) showed that the regression lines for the two groups were not parallel, indicating that the linearity/homogeneity of regression slopes assumption was not satisfied and that ANCOVA was less appropriate. Furthermore, the normality test of the posttest scores (Table 4) showed that the Shapiro–Wilk test produced p = 0.006 (< 0.05), indicating that the posttest data were not normally distributed, although the Kolmogorov–Smirnov test yielded p = 0.188. In this study, decisions were based on the Shapiro–Wilk test, which is more sensitive for small samples; therefore, the normality assumption was considered violated. On the other hand, the homogeneity of variances test (Table 5) using Levene (p = 0.124) and Bartlett (p = 0.692) indicated p > 0.05, meaning that the variances of the two groups were homogeneous and the variance homogeneity assumption was met. Overall, although the homogeneity of variances and covariates assumptions were met, violations of normality and regression-slope homogeneity required the use of nonparametric statistical techniques for hypothesis testing.

Table 3. Covariate Assumption Test (ANOVA) – Pretest

	Sum of Squares	Df	Mean Square	F	P
Kelas	52.8	1	52.8	1.21	0.278
Residuals	1965.1	45	43.7		

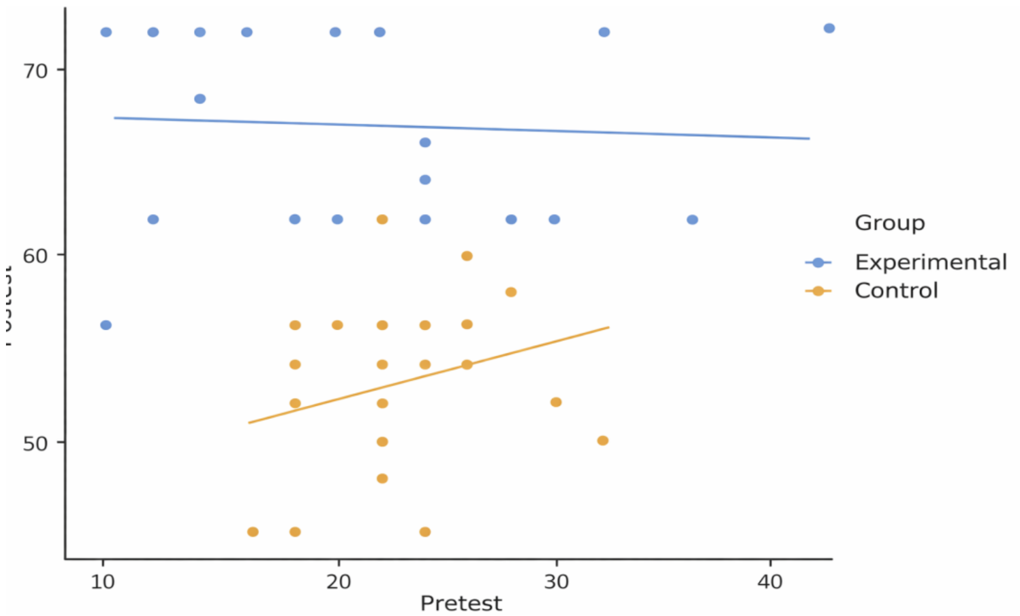

Figure 1. Regression lines between the covariate and the dependent variable in the Control and Experimental classes.

Tabel 4. Normality tests

	Statistic	P
Shapiro-Wilk	0.927	0.006
Kolmogorov-Smirnov	0.159	0.188
Anderson-Darling	1.37	0.001

Tabel 5. Homogeneity of Variances Tests

	Statistic	df	df2	P
Levene's	2.45	1	45	0.124
Bartlett's	0.157	1		0.692

Hypothesis Test Results

Based on the assumption test results, hypothesis testing regarding the effect of the PBL model on students' cognitive learning outcomes was conducted using the nonparametric Kruskal–Wallis test. The analysis results presented in Table 6 show $\chi^2(1) = 32.7$, $p < 0.001$, and a large effect size (ε^2) = 0.711. A p-value < 0.05 indicates that H_0 is rejected and that there is a significant difference between the cognitive learning outcomes of students in the experimental and control classes. The large effect size ($\varepsilon^2 = 0.711$) suggests that this difference is not only statistically significant but also practically meaningful. This finding is consistent with the substantial mean difference in posttest scores between the experimental class (M = 66.8; SD = 5.24) and the control class (M = 53.2; SD = 4.81). Therefore, it can be concluded that implementing Problem-Based Learning (PBL) had a positive and significant effect on improving students' cognitive learning outcomes on environmental pollution material compared with conventional lecture-and-discussion instruction.

Table 6. Kruskal–Wallis Test Results

	χ^2	Df	P	ε^2
Posttest	32.7	1	< .001	0.711

Discussion

The analysis indicates that different instructional models had a significant effect on students' cognitive learning outcomes ($\chi^2(1) = 32.7$; $p < 0.001$), with a large effect size ($\varepsilon^2 = 0.711$). This finding suggests that implementing Problem-Based Learning (PBL) is substantially more effective than conventional lecture-and-discussion instruction in improving cognitive learning outcomes in Biology among Grade X students at MA Miftahul Ulum Bettet, Pamekasan. The mean posttest score difference between the experimental and control classes shows that when students are placed in authentic problem-solving situations, they are encouraged to activate higher-order thinking skills, connect prior concepts with new information, and construct deeper conceptual understanding. This aligns with the characteristics of PBL, which uses contextual problems as the starting point for learning and requires active student engagement in formulating hypotheses, seeking information, analyzing alternative solutions, and drawing conclusions, thereby directly contributing to improved cognitive achievement.

Empirically, these results are consistent with numerous studies that report that PBL positively influences learning outcomes and problem-solving ability. Lutfiah et al. (2021) and Fitriyah and Ghofur (2021) showed that PBL guides learners to solve problems presented by the teacher actively and increases their ability to identify appropriate solutions. Similarly, Cahyani et al. (2021) reported that PBL can develop learners' competencies, increase learning engagement, and guide inquiry both individually and in groups. Comparable findings were reported by Panjaitan (2021), Harahap (2021), and Aliefiyanto (2022), who concluded that PBL improves student learning outcomes by making learning more student-centered, providing space for exchanging information, and supporting the development of problem-solving strategies. Anwar (2021) and Rio (2022) emphasized that PBL not only improves learning outcomes but also provides meaningful learning experiences, promotes student interaction, and increases learning motivation. Thus, the present results reinforce the consistency of prior empirical findings while extending the evidence that PBL is effective in the context of Biology learning in madrasah aliyah, particularly for material on environmental pollution.

The effectiveness of PBL is also strongly supported theoretically. Arends (2007) emphasized that PBL organizes instruction around socially important and personally meaningful problems, leading students to conduct authentic investigations, develop hypotheses, make predictions, analyze information, and draw conclusions. Schmidt (1983) and Tan (2003) explained that PBL presents real-life problems to small groups of students for discussion, exploration, and solution, thereby training learners to internalize problem-solving competencies (Lee & Anderson, 2001) while also building lifelong skills such as teamwork and communication (Woods, 2000). Lynda and Wee (2002) added that the PBL process strongly supports the development of self-directed learning, collaboration, metacognitive thinking skills, and information-seeking competencies, all of which are relevant to contemporary workforce needs. Since its popularization at McMaster University in the 1970s, PBL has continued to develop across disciplines (Tan, 2003; Marinik, 2006; Tan, 2000) and is recognized as empowering students with diverse ability levels to participate collaboratively in problem-solving. The findings of this study show that PBL in the experimental class provided new knowledge, trained students to solve problems more quickly and systematically, and resulted in significantly higher cognitive learning outcomes than the control class. Therefore, PBL is not only relevant as a pedagogical innovation but also as a strategic approach for cognitive and social empowerment in Biology learning at the madrasah aliyah level.

Conclusion

Based on the data analysis and discussion, it can be concluded that implementing the Problem-Based Learning (PBL) model had a significant and practically meaningful effect on the

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cognitive learning outcomes in Biology for Grade X students at MA Miftahul Ulum Bettet, Pamekasan, on the topic of environmental pollution. This is reflected in the difference in mean posttest scores between the experimental class (M = 66.8; SD = 5.24) and the control class (M = 53.2; SD = 4.81), supported by the Kruskal–Wallis test results ($\chi^2(1) = 32.7$; $p < 0.001$; $\varepsilon^2 = 0.711$), indicating that PBL was significantly more effective than conventional lecture-and-discussion instruction. By placing students in authentic problem-solving situations and encouraging active engagement, collaboration, and the development of higher-order thinking skills, PBL was shown to improve conceptual understanding and students' cognitive achievement. Accordingly, PBL is recommended as a relevant and effective learning model for Biology instruction, particularly for contextual topics such as environmental pollution at the madrasah aliyah level.

Recommendation

Based on the research findings, the *Problem-Based Learning* (PBL) model is recommended for Biology instruction, particularly on contextual topics such as environmental pollution at the madrasah aliyah level, as it was shown to significantly and meaningfully improve students' cognitive learning outcomes compared to conventional instruction. By engaging students in authentic problem-solving activities and promoting active participation and collaboration, PBL enhances conceptual understanding and higher-order thinking skills, making it an effective and relevant instructional approach.

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