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The Effect of Problem-Based Learning on Students' Science Learning Outcomes in the Human Respiratory System

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ABSTRACT

This study aimed to examine the effect of Problem-Based Learning (PBL) on students' science learning outcomes in the human respiratory system topic. A quantitative approach was employed using a one-group pretest–posttest design. The participants were 32 eighth-grade students at SMPN 1 Cibinong, Indonesia. Data were collected through a learning outcomes test administered before and after the implementation of PBL. The data were analyzed using a paired-samples t-test to determine the significance of differences between pretest and posttest scores, while the normalized gain (N-Gain) was calculated to assess the magnitude of learning improvement. The results showed a statistically significant difference between students' pretest and posttest scores ($p < .05$), indicating a significant improvement in learning outcomes following the implementation of PBL. Furthermore, the N-Gain score was categorized as high ($\geq .70$), demonstrating substantial improvement in students' mastery of the human respiratory system. These findings indicate that PBL can support the improvement of students' science learning outcomes by engaging them in problem-oriented and active learning processes. The study suggests that PBL can be considered as an alternative instructional approach for teaching complex biological concepts, particularly the human respiratory system, at the junior secondary school level.

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INTRODUCTION

Education plays a fundamental role in developing human potential and improving the quality of individuals and society. In Indonesia, education is not merely oriented toward the transmission of knowledge but is intended to develop students' intellectual, creative, social, and personal capacities. Law No. 20 of 2003 on the National Education System emphasizes that education aims to develop students' potential so that they become knowledgeable, capable, creative, independent, responsible, and democratic individuals. The regulation also emphasizes

that education should be implemented as a process of empowerment and cultural development that encourages students' creativity and active participation in learning. These principles imply that effective classroom instruction should move beyond teacher-centered knowledge transmission toward learning experiences that actively engage students in constructing and applying knowledge.

Science education has an important role in realizing this objective because science learning involves not only the acquisition of factual knowledge but also the development of conceptual understanding, scientific reasoning, inquiry skills, and the ability to apply scientific concepts to real-life situations. Consequently, science instruction at the junior secondary level needs to provide students with opportunities to investigate phenomena, identify problems, interpret evidence, formulate explanations, and make reasoned decisions. Such an orientation is consistent with contemporary science education, which increasingly emphasizes active, inquiry-oriented, and contextually meaningful learning. In this context, learning outcomes should not be understood solely as students' ability to recall scientific facts but also as their ability to understand concepts and apply them to authentic problems.

Nevertheless, achieving meaningful science learning remains challenging. Classroom practices may still emphasize explanation, note-taking, and completion of textbook exercises, which can limit opportunities for students to actively investigate and solve scientific problems. When students primarily receive information from teachers rather than constructing knowledge through inquiry and discussion, they may demonstrate limited conceptual understanding and experience difficulties when required to apply scientific principles in unfamiliar situations. A systematic review of PBL implementation in science education similarly indicates that the effectiveness of student-centered learning is influenced by instructional design, contextual adaptation, teacher preparation, and the learning environment (Mudhofir et al., 2026). Therefore, selecting an instructional model that systematically engages students with meaningful problems is important for improving the quality of science learning.

The human respiratory system is one science topic that requires more than memorization of anatomical structures and biological terminology. Students are expected to understand relationships among respiratory organs, mechanisms of breathing, gas exchange, factors affecting respiratory health, and various respiratory disorders. These concepts involve processes that cannot always be directly observed and may therefore be difficult for students to conceptualize when instruction relies predominantly on verbal explanation or static representations. Learning becomes more meaningful when students are confronted with authentic problems, such as why smoking affects lung function, why respiratory infections can interfere with gas exchange, or why physical activity changes breathing rate. Such problems provide opportunities for students to connect biological concepts with observable phenomena and everyday experiences.

Problem-Based Learning (PBL) offers a theoretically relevant instructional approach for addressing these challenges. PBL positions authentic or ill-structured problems as the starting point of learning and encourages students to identify what they know, determine what they need to learn, investigate relevant information, discuss possible explanations, and formulate solutions. Rather than functioning as passive recipients of information, students are positioned as active participants in the learning process. Through this process, PBL can facilitate conceptual understanding while simultaneously encouraging collaboration, inquiry, critical reasoning, and problem-solving. A recent second-order meta-analysis synthesizing 36 datasets from 22 previous meta-analyses reported a positive overall effect of PBL on students' cognitive and affective learning outcomes, with a mean effect size of $g = 0.726$ (95% CI [0.587,

0.865]). The study also noted that the magnitude of PBL effects can vary according to study quality and contextual characteristics (Koçoğlu & Kanadlı, 2025).

Evidence specifically from science education also supports the potential of PBL to improve students' academic achievement. Uluçınar (2023), through a meta-analysis of 55 experimental studies, found that PBL produced a high effect on academic achievement in science education compared with traditional instructional approaches. Importantly, the findings suggested that PBL effectiveness was observed across different educational levels and science subject areas, although the magnitude of the effect varied among studies. Indonesian research has also reported positive outcomes. For example, Kusuma and Fauziah (2023) investigated PBL among Grade VIII junior secondary students studying the human respiratory system and reported a mean learning outcome of 85.6, with an N-Gain of 0.73, categorized as high. Similarly, Pasinggi et al. (2024) examined PBL for the human respiratory system among Grade VIII students and reported improvements in science learning outcomes following implementation of the model. More recent evidence from Grade VIII students at SMP Imelda Medan also indicates that PBL assisted by animated video media significantly improved learning outcomes on the human respiratory system compared with the instructional condition used in the study (Silaban et al., 2025).

The evidence is not limited to learning outcomes. Studies have indicated that PBL can support broader learning competencies associated with science learning. For example, research on the respiratory system has examined PBL in relation to science process skills, demonstrating the relevance of problem-centered learning for engaging students in scientific activities (Martin et al., 2025). Furthermore, recent research has explored the integration of PBL with STEM approaches to strengthen scientific argumentation in respiratory-system learning, suggesting that problem-centered instruction can provide a meaningful environment for students to construct explanations supported by evidence (Shofiyah et al., 2025). These findings reinforce the pedagogical rationale for using authentic problems as an entry point for learning biological concepts.

However, several gaps remain. First, although numerous studies have established the general effectiveness of PBL, the magnitude of its effect may depend on the learning context, instructional implementation, subject matter, student characteristics, and assessment procedures. The recent meta-analytic literature emphasizes substantial variation among PBL studies, indicating that evidence from one educational context cannot automatically be generalized to another (Koçoğlu & Kanadlı, 2025). Second, studies focusing specifically on the human respiratory system at the junior secondary level remain relatively limited compared with the broader literature on PBL in science education. Existing studies have frequently employed classroom action research or one-group pretest-posttest designs, while comparative evidence using experimental and control groups can provide stronger evidence regarding the effect of PBL on learning outcomes. Third, some recent studies have incorporated additional interventions, such as animated videos, augmented reality, or STEM integration. While these innovations are valuable, they make it more difficult to isolate the contribution of the PBL model itself to students' science learning outcomes.

Therefore, further empirical investigation is warranted to examine the effect of PBL as an instructional model on junior secondary students' science learning outcomes in the human respiratory system without conflating its effect with additional technological or instructional interventions. Such research is particularly relevant because the topic requires students to connect biological concepts with real-world health problems and observable physiological phenomena. By engaging students in authentic problem situations, investigation, discussion, evidence-based reasoning, and solution formulation, PBL has the potential to transform

respiratory-system learning from a predominantly conceptual and memorization-oriented activity into a more active and meaningful learning experience.

Accordingly, this study aims to examine the effect of the Problem-Based Learning model on students' science learning outcomes in the human respiratory system. The study is expected to provide empirical evidence concerning the applicability of PBL in junior secondary science education and to contribute to the growing literature on instructional approaches that promote active and meaningful science learning. The findings may also provide practical implications for science teachers seeking instructional strategies that enhance students' understanding and achievement in learning biological concepts, particularly those involving complex and abstract physiological processes.

METHOD

1. Research Design

This study employed a quantitative approach using a pre-experimental one-group pretest–posttest design to examine changes in students' science learning outcomes following the implementation of Problem-Based Learning (PBL). A quantitative approach was selected because the study involved numerical measurement of students' learning outcomes and statistical analysis to determine differences between measurements taken before and after the intervention (Creswell & Creswell, 2018).

In this design, the same group of students completed a pretest before the implementation of PBL and a posttest after the intervention. The design can be represented as:

$O_1 \rightarrow X \rightarrow O_2$

where O_1 represents the pretest, X represents the PBL intervention, and O_2 represents the posttest. The difference between pretest and posttest scores was used to determine whether students' science learning outcomes changed following the implementation of PBL. Because the same students were measured at two time points, the observations were treated as paired or dependent measurements.

This design is appropriate for identifying changes within the participating group; however, because it does not include a separate control group or random assignment, changes in students' scores cannot be attributed exclusively to PBL without considering potential alternative explanations (Creswell & Creswell, 2018).

2. Participants and Research Procedure

The participants were students enrolled in Grade VIII at SMPN 1 Cibinong. The research focused on the human respiratory system, which was taught using the Problem-Based Learning model. The intervention was implemented through learning activities that engaged students in identifying authentic problems, investigating relevant scientific concepts, discussing possible explanations, developing solutions, and presenting their findings.

Before the intervention, students were administered a pretest to measure their initial understanding of the human respiratory system. The PBL intervention was subsequently implemented during the predetermined instructional period. After completion of the intervention, the students were administered a posttest using an equivalent assessment framework to determine changes in their learning outcomes.

3. Research Instrument

Data were collected using a multiple-choice science achievement test focusing on the human respiratory system. The test was designed to measure students' cognitive learning outcomes in accordance with the learning objectives of the topic. The use of a structured test is consistent with quantitative educational research, in which standardized instruments are used to obtain measurable data for statistical analysis (Arifin, 2012).

Before being administered to the participants, the instrument was subjected to content validity assessment by experts to determine the relevance, clarity, and appropriateness of the items to the intended learning outcomes. Items that did not meet the required criteria were revised or excluded before the instrument was used in the main study. Instrument reliability was also examined to determine the consistency of the test scores.

4. Data Collection Procedure

Data collection was conducted in three stages. First, the pretest was administered to establish students' baseline science learning outcomes. Second, students participated in learning activities using the Problem-Based Learning model. The PBL implementation emphasized problem identification, investigation, discussion, formulation of solutions, and communication of findings. Third, the posttest was administered after the intervention to measure students' learning outcomes following the PBL implementation.

The use of pretest and posttest measurements allowed the researchers to compare students' performance within the same group before and after the instructional intervention.

5. Data Analysis

The data were analyzed using descriptive and inferential statistics. Descriptive statistics, including the mean, standard deviation, minimum, and maximum scores, were calculated for both the pretest and posttest results.

Before conducting the inferential analysis, the distribution of the difference scores between the posttest and pretest was examined to assess the assumption of normality. Because the same participants provided both measurements, the paired-samples t-test was employed when the normality assumption was satisfied. The paired-samples t-test evaluates whether the mean difference between two related measurements differs significantly from zero (Kim, 2015).

6. The statistical hypothesis was formulated as follows:

H_0: There is no significant difference between students' mean science learning outcomes before and after the implementation of PBL.

H_1: There is a significant difference between students' mean science learning outcomes before and after the implementation of PBL.

The significance level was set at $\alpha = .05$. A *p*-value below .05 was interpreted as evidence of a statistically significant difference between the pretest and posttest scores.

In addition to statistical significance, an effect size was calculated to describe the magnitude of the observed change. For paired measurements, Cohen's *d* for dependent samples can be calculated using the mean of the difference scores divided by the standard deviation of those difference scores (Lakens, 2013). Reporting an effect size provides information about the magnitude of the change beyond statistical significance and is therefore useful for interpreting the practical importance of the intervention.

All statistical analyses were performed using statistical software, and the results were reported using the mean difference, *t*-value, degrees of freedom, *p*-value, confidence interval where applicable, and effect size.

RESULTS AND DISCUSSION

3.1. Data Completeness and Normality

The analysis involved 32 students who completed both the pretest and posttest. The case-processing results showed that all observations were valid, with no missing data. Thus, all 32 paired observations were included in the subsequent analysis.

The normality test using the Shapiro–Wilk statistic indicated that both the pretest and posttest scores met the normality assumption. The significance value was 0.268 for the pretest and 0.085 for the posttest, both exceeding the 0.05 significance level. Therefore, the

distribution of the two sets of scores did not significantly deviate from normality, allowing the use of a paired-samples *t*-test to examine the difference between students' pretest and posttest scores.

3.2. Descriptive Statistics of Pretest and Posttest Scores

The descriptive results showed an improvement in students' science learning outcomes following the implementation of Problem-Based Learning (PBL). The mean pretest score was 77.88 (SD = 6.724), whereas the mean posttest score increased to 85.50 (SD = 5.292). Thus, the mean score increased by 7.63 points, representing approximately a 9.79% increase relative to the pretest mean.

Importantly, the standard deviation decreased from 6.724 to 5.292. This indicates that, in addition to increasing the average achievement, the posttest scores were more concentrated around the mean. In other words, the learning outcomes became relatively more homogeneous after the instructional intervention.

3.3. Paired-Samples *t*-Test

The paired-samples *t*-test revealed a statistically significant difference between the pretest and posttest scores, $t(31) = -7.761$, $p < .001$. The mean paired difference was −7.625, with a 95% confidence interval ranging from −9.629 to −5.621.

These results indicate that students' science learning outcomes after participating in PBL were significantly higher than their outcomes before the intervention. The magnitude of the observed difference is also educationally meaningful. Based on the paired data, the estimated standardized effect is approximately Cohen's d = 1.37, indicating a large within-group effect. Nevertheless, because the present study uses a one-group pretest–posttest design, the improvement should be interpreted as an association with the PBL intervention rather than definitive causal evidence, because there is no control group to rule out alternative explanations such as maturation, testing effects, or exposure to other learning activities.

3.4. N-Gain Analysis

The normalized gain analysis showed a mean N-Gain of 0.8153, equivalent to 81.53% when expressed as a percentage. The individual N-Gain values ranged from approximately 69.67% to 88.55%, with a standard deviation of approximately 4.50 percentage points.

Using Hake's conventional classification, an N-Gain of 0.8153 falls within the high-gain category. The result suggests that the increase was not limited to a small number of students but occurred relatively consistently across the participants. The relatively small standard deviation further indicates that the improvement was comparatively homogeneous among the 32 students.

4. Discussion

The findings demonstrate a substantial improvement in students' science learning outcomes after the implementation of Problem-Based Learning on the human respiratory system. The mean score increased from 77.88 in the pretest to 85.50 in the posttest, while the paired-samples *t*-test showed a statistically significant difference, $t(31) = -7.761$, $p < .001$. More importantly, the N-Gain of 0.8153 indicates a high level of normalized improvement. These findings suggest that PBL provided a learning environment that supported students in developing a more integrated understanding of the respiratory system.

The improvement can be theoretically explained by the fundamental characteristics of PBL. Rather than receiving information primarily through direct explanation, students are confronted with meaningful problems that require them to identify what they know, determine what they need to learn, seek relevant information, discuss possible explanations, and formulate solutions. This sequence encourages students to connect new scientific concepts with prior

knowledge. In the context of the human respiratory system, problems related to breathing difficulties, smoking, air pollution, respiratory diseases, or changes in respiratory rate can provide authentic contexts through which students understand the relationship between respiratory organs, mechanisms of breathing, gas exchange, and factors affecting respiratory health.

The present findings are consistent with broader empirical evidence. A meta-analysis involving 55 experimental studies found that PBL had a high effect on academic achievement in science education compared with traditional instructional approaches (Uluçınar, 2023). This provides broader support for the present finding because the observed improvement is consistent with evidence across multiple science-learning contexts rather than being restricted to a single classroom.

Recent Indonesian research also provides evidence that PBL can improve science learning outcomes. Panjaitan and Puspita (2025), for example, reported that combining PBL with Teaching at the Right Level produced a mean posttest score of 91.73 compared with 68.53 in the conventional-learning group, with a significant difference between the groups. Their experimental class also achieved an N-Gain of 86%, classified as high. Similarly, Kurniawan et al. (2025) reported positive effects of PBL on science-process skills and cognitive learning outcomes, reinforcing the argument that PBL can facilitate not only content acquisition but also scientific engagement and reasoning.

a. PBL and Learning of the Human Respiratory System

The particularly strong improvement found in this study may also be related to the characteristics of the human respiratory system as a learning topic. Several concepts within this topic are difficult to observe directly because processes such as gas exchange, oxygen transport, and cellular-level interactions cannot be readily experienced through ordinary classroom observation. Consequently, learning activities that begin with authentic problems can help students move from observable phenomena toward scientific explanations.

Recent studies specifically addressing the respiratory system provide relevant evidence. Silaban et al. (2025) found that PBL assisted by animation videos significantly improved students' learning outcomes on the human respiratory system. Likewise, research on PBL combined with mind mapping reported significantly better cognitive learning outcomes in the experimental group, with an N-Gain of 0.77 compared with 0.38 in the control group. These findings are particularly relevant because they concern the same broad biological topic and suggest that PBL can help students organize and apply complex conceptual knowledge.

Pasinggi et al. (2024) likewise reported improvement in students' learning outcomes on the human respiratory system following the implementation of PBL combined with discussion activities. The convergence between these findings and the present study strengthens the interpretation that respiratory-system instruction can benefit from student-centered learning that requires learners to investigate and discuss contextual problems.

Another possible explanation concerns active knowledge construction. In PBL, students are required to explain phenomena, compare information, evaluate possible solutions, and communicate their reasoning. These activities encourage deeper cognitive processing than simply memorizing the names and functions of respiratory organs. This interpretation is also supported by recent research showing that PBL can promote students' scientific-process skills and cognitive outcomes (Kurniawan et al., 2025).

b. PBL, Scientific Reasoning, and Student Engagement

The effectiveness of PBL should not be understood solely in terms of increased test scores. The instructional mechanism is also important. PBL shifts classroom activity from teacher-dominated knowledge transmission toward student investigation and collaborative

problem solving. Students must determine the nature of a problem, identify relevant information, formulate explanations, and evaluate whether their proposed explanations are scientifically reasonable.

This characteristic is especially relevant to science education because science learning requires students to use evidence to explain phenomena rather than merely recall factual information. Recent studies on PBL in respiratory-system learning have reported improvements in related outcomes, including critical thinking and science-process skills. For example, Jannah and Saifuddin (2024) examined problem-based blended learning in respiratory-system instruction and emphasized its relevance to the development of students' critical-thinking skills. Research using PBL with augmented reality on the respiratory system has likewise examined critical-thinking and learning-motivation outcomes, illustrating the increasing integration of PBL with technology-supported learning environments.

Therefore, the improvement in the present study may reflect not only greater exposure to content but also changes in the way students processed and applied information. When students encounter a problem that resembles a real-life respiratory health issue, they have a reason to seek explanations and integrate concepts. Such contextualization can make abstract biological processes more meaningful.

c. Consistency of the Learning Gains

Another important finding is the reduction in the standard deviation from 6.724 on the pretest to 5.292 on the posttest. This pattern suggests that the intervention was associated with both higher average achievement and somewhat greater consistency among students' scores. The finding may indicate that collaborative problem-solving activities provided opportunities for students with different initial levels of understanding to interact, exchange explanations, and access learning resources.

However, this interpretation should be made cautiously. The reduction in score variation alone cannot establish that PBL reduced achievement disparities because other factors may also contribute to changes in score dispersion. Future studies could examine this issue more explicitly by including measures of student participation, prior knowledge, learning motivation, and group interaction.

d. Educational Implications

The findings have several implications for science teaching at the junior secondary level. First, PBL can be considered as an instructional approach for topics that contain complex relationships between scientific concepts and everyday phenomena. The human respiratory system is particularly suitable because students frequently encounter respiratory-health issues in their daily lives.

Second, the findings suggest that PBL should not be implemented merely by assigning students a problem. The learning problem needs to be sufficiently contextual, scientifically meaningful, and appropriate to students' cognitive development. Teachers need to provide scaffolding so that students can identify relevant information, formulate explanations, evaluate evidence, and communicate their conclusions.

Third, PBL can be strengthened through appropriate learning media. Recent studies have combined PBL with animation, mind mapping, augmented reality, and digital learning resources in respiratory-system instruction. This suggests that the effectiveness of PBL may be further supported when abstract biological processes are represented through visual or interactive media.

e. Interpretation and Limitation

Although the statistical results provide strong evidence of improvement within the participating group, the research design needs to be considered when interpreting the findings.

Because the available data consist of a single group of 32 students measured before and after the intervention, the significant *t*-test and high N-Gain demonstrate pretest-to-posttest improvement, but they do not by themselves establish that PBL was the sole cause of the improvement. A randomized or quasi-experimental study involving a control group would provide stronger evidence of the specific effect of PBL.

In addition, the paired-samples correlation of $r = .595$ ($p < .001$) indicates a moderate positive relationship between students' pretest and posttest scores. This result shows that students' relative performance was somewhat consistent across the two measurements. However, correlation should not be interpreted as evidence of the effectiveness of PBL; the evidence for improvement comes primarily from the paired mean difference and its statistical test.

Overall, the findings indicate that implementation of PBL was accompanied by a statistically significant and relatively large improvement in students' science learning outcomes, with a high normalized gain on the human respiratory system topic. The findings are broadly consistent with recent empirical studies and meta-analytic evidence supporting PBL as a student-centered approach for science learning.

CONCLUSION

Based on the results of the paired-samples *t*-test and N-gain analysis, the implementation of the learning strategy was associated with a significant improvement in students' learning outcomes. The mean score increased from 77.88 on the pretest to 85.50 on the posttest, representing a mean gain of 7.625 points. The paired-samples *t*-test yielded $t = -7.761$ with $p < .001$, indicating that the difference between pretest and posttest scores was statistically significant.

Furthermore, the mean N-gain score of 81.53% was categorized as high, indicating substantial improvement in students' learning outcomes following the learning intervention. The normality and homogeneity assumptions were also satisfied, supporting the appropriateness of the statistical analysis. Overall, the findings indicate that the learning strategy implemented in this study contributed to a significant improvement in students' learning outcomes. However, the findings should be interpreted within the context of the study design and participants, and further research involving larger samples, comparison groups, and longer intervention periods is recommended to examine the consistency and generalizability of the findings.

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