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Student Learning Outcomes in Digestive Systems Material via Deep Learning-Based Problem-Based Learning in High School

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ABSTRACT

The low effectiveness of conventional learning models in improving students' in-depth understanding and learning outcomes in the digestive system often results in suboptimal learning outcomes. This study aims to determine the effect of the Problem-Based Learning (PBL) model with a deep learning approach on student learning outcomes in the digestive system. The method used was a quasi-experimental with a pretest-posttest control group design. The study population included six classes with samples consisting of two classes: Class XI C as the experimental class (PBL model with a deep learning approach) and Class XI D as the control class (direct instruction method) at High School 1 Batang Kuis. The research instruments included essay tests and student response questionnaires. Results: The findings showed an increase in the average score in the experimental class from 47.1 to 87.5 (an increase of 85.7%), higher than the control class which increased from 46.7 to 81.2 (an increase of 73.8%). The learning completion rate in the experimental class reached 34 students, surpassing the control class which consisted of 27 students. Student responses to the deep learning approach were categorized as very positive, supported by indicators of mindful learning (82%), meaningful learning (72%), and joyful learning (89%). The hypothesis test showed a significant value of 3.649 x 10^{-5} (<0.05), confirming a significant effect. Practically, this study proves that the integration of PBL and the deep learning approach is an effective strategy for improving learning outcomes and creating meaningful learning experiences for students in complex biology material.

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1. INTRODUCTION

Education in the 21st century demands a fundamental transformation in the entire learning process in schools (González-Pérez & Ramírez-Montoya, 2022; Zebua, 2025). Students are no longer simply expected to memorize reams of information but are instead required to develop sharp critical and analytical thinking skills (Hassan et al., 2025; Sarigoz, 2023). The ability to apply knowledge in real-life contexts has become a key parameter for the success of modern education, specifically designed to address increasingly complex global dynamics.

In science disciplines, particularly biology, the essence of learning should emphasize in-depth conceptual understanding and the development of systematic problem-solving skills (Muawanah et al., 2025; Papaneophytou & Nicolaou, 2025). Ideally, biology learning integrates mastery of scientific facts with higher-order thinking skills. This aims to enable students to understand natural phenomena comprehensively and holistically (Ardhana et al., 2025).

However, the reality on the ground demonstrates a significant gap between this idealism and learning practices, which are still dominated by a teacher-centered approach. This conventional instructional pattern tends to position students as merely passive recipients of information (Keiler, 2018; Muganga & Ssenkusu, 2019). As a result, student engagement in intellectual exploration activities in the classroom is very limited and underdeveloped.

This lack of active engagement in participatory learning ultimately negatively impacts students' conceptual understanding of the material being taught (Haron et al., 2017; Ma, 2023). When students are not emotionally and cognitively engaged, knowledge internalization is suboptimal. This condition directly results in students' learning outcomes often failing to meet established competency standards (Peng et al., 2021).

This problem of low understanding is particularly evident in the human digestive system. This material is abstract because it involves sequential and complex physiological processes (Li et al., 2023). The complexity of organ function and the specific roles of various enzymes are often difficult for students to visualize, leading them to view the material as a mere memorization burden rather than a logical system (Sari & Tenriwaru, 2023).

To address this problem, the use of innovative learning models such as problem-based learning (PBL) is urgently needed. The PBL model places real-world problems as the primary trigger in the learning process (Hasbi & Fitri, 2023; Muzaini et al., 2022; Satriani et al., 2021). Through problem scenarios, students are effectively trained to hone their critical thinking skills and collaborative abilities in formulating appropriate solutions (Anggraeni et al., 2023; Shamdas, 2023; Suradika et al., 2023; Suwono et al., 2023). In addition to selecting the right model, the integration of a deep learning approach is a key element in strengthening students' understanding (Weng et al., 2023). This approach emphasizes the ability to connect various ideas and concepts comprehensively. With deep learning, students not only absorb information superficially but are able to build meaningful knowledge structures that remain in their memory for a long time (Feriyanto & Anjariyah, 2024; Kovač et al., 2025; Taye, 2023).

Objective conditions in the field, based on observations conducted at High School 1 Batang Kuis, indicate that the lecture method still dominates biology instruction. This results in low student productivity in class and a lack of enthusiasm for exploring the material. This situation underscores the need for more progressive pedagogical interventions that are relevant to current student needs. Building upon this background, this study was conducted to examine the effect of the PBL model with a deep learning approach on the learning outcomes of 11th grade science students in the digestive system topic in the 2025/2026 academic year. This research is expected to be a concrete effort to improve the quality of instruction at High School 1 Batang Kuis and make a positive contribution to innovation in biology learning more broadly.

2. METHOD

In this study, the researcher used a quantitative research approach to determine the effect of the Problem-Based Learning model with a deep learning approach. The research design employed a quasi-experimental design, which aims to observe the effects of a treatment under controlled conditions. This study provided different treatments for two classes: the experimental group and the control group. The experimental group was given the Problem-Based Learning treatment with a deep learning approach, while the control group received the direct interaction learning model.

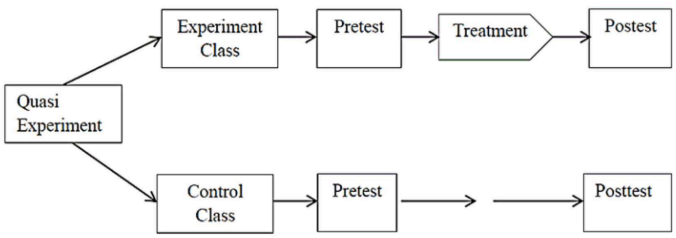

Figure 1. Pretest-Posttest Control Group Design

This study involved two main variables: the independent variable, the Problem-Based Learning (PBL) model with a deep learning approach, and the dependent variable, which focused on the learning outcomes of eleventh-grade science students at High School 1 Batang Kuis in the digestive system. The study population included all eleventh-grade science students at High School 1 Batang Kuis, Deli Serdang Regency, in the 2025/2026 academic year. The sample was selected using a purposive sampling technique, considering similarities in student characteristics, particularly in initial learning outcomes, and similarities in biology teachers teaching the classes. The selected sample consisted of two classes with a total of 72 respondents: class XI D as the experimental class and class XI C as the control class, each with 36 students.

The data collection procedure was systematically designed, beginning with a trial run of the research instrument and followed by processing the results to ensure data validity and reliability. The research was then implemented in parallel in experimental and control classes. After collecting field data, the next stage is data processing, which includes in-depth analysis of the research results, transforming the data into comprehensive descriptions, and preparing a credible final research report.

To test the research hypotheses and estimate the magnitude of the influence between variables, a series of rigorous statistical analyses were used. The initial stage began with prerequisite analysis tests, including normality and homogeneity tests to ensure data distribution. If the data met the criteria for normality and homogeneity, the analysis continued with hypothesis testing using parametric statistics, namely the t-test. To improve accuracy and efficiency throughout the statistical data processing process, the author optimized the use of Microsoft Excel 2021.

3. RESULTS AND DISCUSSION

Results

The results of statistical calculations obtained the average initial test of the experimental class is 47.1 while the initial test value in the control class is 46.7 from these results obtained; the difference in the average of the experimental class is not too far. The difference between the averages of the two classes is 0.4. From the results of the initial tests of the experimental class students and the control class students will be presented in a frequency distribution table starting from the lowest value to the highest value obtained by students in each class.

Table 1. Pretest Results of Experimental Class and Control Class

Class	N	N-Min	N-Max	Average Pretest Score
Experimental Class	36	35	60	47.1
Control Class	36	35	60	46.7

Table 2. Posttest Results of Experimental Class and Control Class

Class	N	N-Min	N-Max	Average Posttest Score
Experimental Class	36	78	100	87.5
Control Class	36	69	95	81.2

The data analysis revealed a significant difference in achievement between the two groups of study subjects. The experimental class achieved a final average score of 87.5, indicating an advantage over the control class, which had an average score of 81.2. Comparatively, the experimental class recorded more impressive learning outcomes, with a 40.4% increase, from a baseline score of 47.1 to 87.5 on the final test.

On the other hand, the control class showed a lower improvement trend, at 34.5%, with a score moving from 46.7 to 81.2. This difference in the margin of improvement between the two classes indicates that the treatment given to the experimental group had a greater impact on students' mastery of the material. These data confirm that the intervention in the experimental class was empirically more effective in boosting academic performance compared to the method applied to the control class.

Pretest and Posttest Results

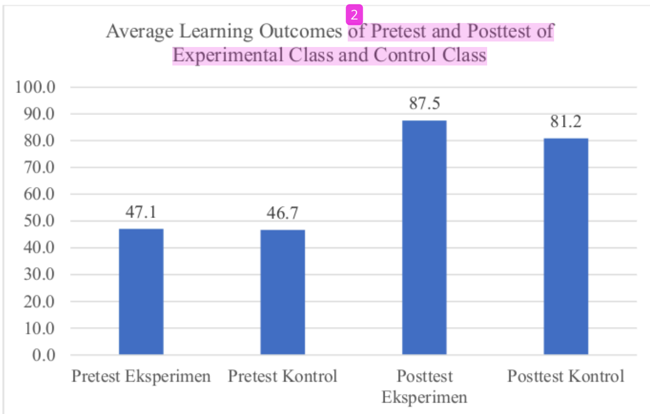

Figure 2. Average Learning Outcomes of Pretest and Posttest of Experimental Class and Control Class

The data presented in Figure 2 shows that the average pretest scores indicate relatively equal initial conditions between the two groups of study subjects. The experimental class recorded an average score of 47.1, slightly higher than the control class's score of 46.7. This similarity in initial scores indicates that both groups had a balanced knowledge base before being given the different treatments, allowing comparisons of the results to be considered valid and objective.

Significant improvements in learning outcomes were evident in the post-treatment phase. The experimental class, which implemented the learning innovation, achieved an average posttest score of 87.5, surpassing the control class, which achieved an average score of 80.9. This substantial difference in scores demonstrates the clear effectiveness of the intervention, with students in the experimental group being able to absorb and apply the digestive system material significantly better than those in the control group.

Overall, this comparison of research results confirms that student academic performance significantly improved through the implementation of the Problem-Based Learning (PBL) model integrated with the Deep Learning approach. This success confirms that the synergy between real-world problem solving and in-depth conceptual exploration is more effective in supporting student mastery of the material. Therefore, this approach deserves consideration as a superior instructional strategy to replace conventional methods in biology learning.

Student Response Questionnaire Results

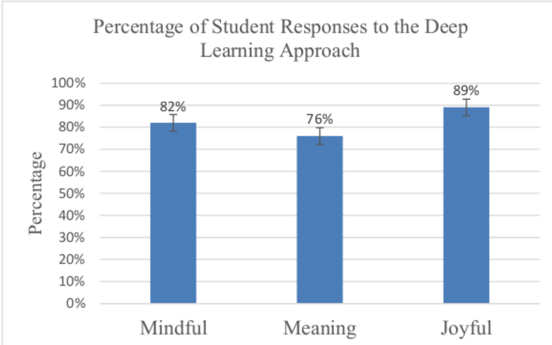

Figure 3. Student Responses to the Deep Learning Approach

The analysis of student response questionnaires revealed a very high level of acceptance of the learning implementation that integrates aspects of mindful learning, meaningful learning, and joyful learning. For the mindful learning indicator, 82% strongly agreed, while the meaningful learning aspect received a score of 76% in the agree category. The most significant response was seen as the joyful learning indicator, which reached 89% in the strongly agree category, reflecting students' enthusiasm and comfort during the learning process using the deep learning approach.

The high percentages across all indicators confirm that the deep learning approach not only focuses on cognitive mastery but also successfully creates meaningful and enjoyable learning experiences for students. Based on these positive perceptions, it can be concluded that this approach has an effective and contributive influence on improving student learning outcomes. The alignment between emotional engagement and deep understanding of the material is a key factor supporting the success of this learning model in the classroom.

Hypothesis Test Results

Table 3. Hypothesis Test Results (Independent Sample T-Test)

Statistical Analysis	Value	Criteria	Decision
t-test	4.41	t_count > t_table (1.99)	H_0 Rejected, H_1 Accepted
Significance (p-value)	$3{,}64 \times 10^{-5}$	p<0,05	Significant

The table above represents that the results of the independent sample t-test show a t_count value of 4.41, which is significantly greater than the t_table of 1.99. In addition, the significance obtained is far below the threshold of 0.05 ($3.64 \times 10^{-5} < 0.05$). These findings provide a strong statistical basis for concluding that the application of the Problem-Based Learning (PBL) model with a deep learning approach has a significant influence on the learning outcomes of class XI IPA students at High School 1 Batang Kuis on the digestive system material.

Discussion

Analysis of the initial conditions showed that both groups of study subjects started from an equal starting point, with an average pretest score of 47.1 for the experimental class and 46.7 for the control class. This very small average difference (0.4) confirmed that there was no significant gap in initial understanding between the two classes before the intervention, allowing the results of the study to be objectively attributed to the treatment. This initial equivalence is crucial to ensure the internal validity of the study, in line with the principles of experimental methodology, which state that control of input variables is necessary to ensure that differences in results are solely the result of the learning treatment.

A significant improvement in learning outcomes was seen after the intervention, with the experimental class achieving an average posttest score of 87.5, outperforming the control class, which achieved a score of 81.2. The experimental class recorded a margin of improvement of 40.4%, compared to only 34.5% for the control class. This data empirically demonstrates that the synergy between the Problem-Based Learning (PBL) model and the deep learning approach has a stronger impact on helping students master the digestive system material compared to conventional learning methods. These findings reinforce previous studies that suggest that problem-based learning models are effective in improving students' cognitive structure because they don't simply receive information but rather construct knowledge through problem-solving activities (Shongwe, 2024; Valsecchi et al., 2024).

This success is supported by the results of the hypothesis test, which showed a calculated t-value of 4.41, far exceeding the t-table of 1.99, with a very low significance level ($3.64 \times 10^{-5} < 0.05$). This statistical significance confirms that the implementation of real-world problem-oriented PBL can encourage in-depth exploration of concepts. This is relevant to constructivism theory, which emphasizes that deep learning occurs when students actively engage in linking new concepts to real-life experiences (Vogel-Walcutt et al., 2011; Yadav, 2025), allowing abstract digestive system material to be understood more concretely and systematically.

In addition to cognitive outcomes, the effectiveness of this intervention was also confirmed by positive student responses to the effective and experiential aspects of learning through the deep learning approach. Student responses demonstrated a very high level of acceptance, particularly for the joyful learning indicator, which reached 89%, followed by mindful learning at 82% and meaningful learning at 76%. These figures reflect that students felt enthusiastic and comfortable and found the learning process more meaningful. This aligns with the theory of meaningful learning, which states that intrinsic motivation and enjoyment in learning are key catalysts for long-term knowledge retention (Agra et al., 2019; Hsbollah & Hassan, 2022).

In conclusion, the integration of the PBL model and the deep learning approach proved successful in creating a holistic learning experience for 11th-grade science students at High School 1 Batang Kuis. The alignment of emotional engagement and in-depth conceptual understanding proved effective in replacing the dominance of conventional, passive lecture methods. These findings provide an important contribution to biology education practice, demonstrating that in-depth exploration of the digestive system through authentic problems not only improves test scores but also shifts students' perceptions of science to become more positive and relevant.

It can be concluded that the alignment between emotional engagement and deep understanding is a key factor in the success of this model. The deep learning approach not only focuses on surface mastery of the material but also successfully creates a fun and memorable learning experience for students. Therefore, the integration of PBL with the deep learning approach has proven effective in improving academic performance and the quality of biology learning in the classroom.

This research makes a significant contribution to the development of pedagogical innovation at the secondary school level, particularly in strengthening the integration between the Problem-Based Learning (PBL) model and the deep learning approach to improve students' scientific literacy in complex biology material. These findings demonstrate that the synergy between real-world problem solving and mindful, meaningful, and joyful learning is not only empirically effective in improving cognitive learning outcomes to an average of 87.5, but also successfully creates a positive learning atmosphere and increases student enthusiasm. Practically, this study provides a strategic reference for educators at High School 1 Batang Kuis and other institutions in implementing instructional strategies oriented towards depth of understanding, thereby minimizing reliance on conventional lecture methods and mere memorization.

4. CONCLUSION

This study concluded that the implementation of the Problem-Based Learning (PBL) model with a deep learning approach was significantly more effective in improving student learning outcomes in the digestive system compared to conventional methods (direct instruction). This was empirically proven through a hypothesis test with a significant value of 3.649 x 10^-5 (<0.05) and an increase in the average grade of the experimental class to 85.7% (from 47.1 to 87.5), outperforming the control class. In addition to improving academic performance and student learning completion rates, this integration also succeeded in creating a positive learning experience. This was reflected in the very high student responses to indicators of joyful learning (89%), mindful learning (82%), and meaningful learning (72%). Thus, the synergy between PBL and deep learning is a strategic solution to address the low conceptual understanding of complex biology material, while simultaneously increasing student active engagement and learning satisfaction at the secondary school level.

As a recommendation, it is recommended that educators integrate the Problem-Based Learning (PBL) model with a deep learning approach by designing contextual problem scenarios to create meaningful and enjoyable learning experiences, especially for complex biology materials. Schools are expected to support this innovation by providing adequate discussion facilities and organizing workshops for teachers, while students are encouraged to be more active in critical reflection and collaborative discussions to strengthen their mastery of scientific concepts in depth. Furthermore, future researchers can expand the scope of research to different materials and populations, and explore additional variables such as critical thinking skills, scientific literacy, and long-term memory retention to enrich empirical evidence regarding the effectiveness of this learning synergy.

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