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Exploration of Problem-Based Experimental Learning as a Strategy for Strengthening Science Process Skills in the Digestive System Material

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ABSTRACT

Purpose of the study: This study aims to analyze the influence of the experimental method with a problem-based learning approach on students' science process skills in the concept of the digestive system, as well as to measure the effectiveness of implementing this learning strategy in improving students' scientific abilities through active, contextual, and inquiry-based learning activities.

Methodology: Quasi-experimental method, pretest-posttest control group design, purposive sampling, science process skills essay test, non-participatory observation sheet, normal gain test, Liliefors test, Fisher test, t-test, quantitative statistical analysis, digestive system learning tools, experimental worksheets, question validation instruments, statistical data processing software, and observations by biology subject teachers.

Main Findings: The application of the experimental method with a problem-based learning approach showed a significant increase in students' science process skills. The experimental group achieved a higher normal gain than the control group. The research data were normally distributed and homogeneous. The results of the hypothesis test showed a significant difference in the final test results between the two groups, confirming the effectiveness of the learning strategy in improving science process skills in the digestive system topic.

Novelty/Originality of this study: The novelty of this research lies in the integration of experimental methods with a problem-based learning approach specifically for the digestive system to develop science process skills. This study expands understanding of investigation-based biology learning strategies and provides an innovative learning model that can be used to enhance students' scientific competence in a more structured manner.

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1. INTRODUCTION

Science education plays a crucial role in developing critical, logical, and systematic thinking skills in students [1], [2]. Through science learning, students are expected to not only understand theoretical concepts but also be able to apply them in everyday life. An effective science learning process must provide opportunities for students to actively participate in discovering knowledge [3], [4]. This involvement can occur through observation, experimentation, data analysis, and drawing conclusions. Therefore, science learning needs to be innovatively designed to develop students' scientific thinking skills [5], [6].

One important skill that must be developed in science learning is science process skills [7], [8]. These skills include observing, classifying, measuring, formulating hypotheses, designing experiments, interpreting data, and communicating results. Science process skills provide the foundation for students to understand the nature of science as a whole [7], [9]. Through these skills, students can build conceptual understanding based on direct experience. Mastery of science process skills also contributes to improved scientific problem-solving abilities [10], [11].

In school learning practices, the development of science process skills still faces various challenges. The learning process is often dominated by teacher-centered lectures [12], [13]. This condition leads to students being passive and lacking direct learning experiences. Learning that overemphasizes memorization of concepts makes it difficult for students to connect theory to real-world phenomena [14], [15]. As a result, students' science process skills are not optimally developed.

The digestive system is a biological concept that requires in-depth understanding because it relates to the structure, function, and working mechanisms of body organs [16], [17]. This concept cannot be grasped solely through verbal explanations or visualizations in textbooks. Students need learning experiences that allow them to explore and directly observe phenomena related to the digestive system [18], [19]. Experimental activities can help students understand biological processes more concretely. Therefore, the digestive system is highly suitable for teaching through an active and investigative learning approach.

The experimental method is a learning strategy that can encourage active student involvement in the learning process [20], [21]. Through experiments, students can make direct observations, collect data, test hypotheses, and draw conclusions based on empirical evidence. This method provides students with the opportunity to experience the scientific process firsthand [22], [23]. In addition to enhancing conceptual understanding, experiments also foster critical and analytical thinking skills [24], [25]. Therefore, the application of the experimental method is highly relevant for developing science process skills.

On the other hand, a problem-based learning approach provides space for students to think critically in solving contextual problems [26], [27]. This approach places students at the center of learning through problem identification, information analysis, discussion, and solution-finding. Problem-based learning can foster curiosity and reflective thinking skills [28], [29]. When combined with the experimental method, this approach has the potential to create a more meaningful learning experience. The integration of the two is believed to strengthen students' science process skills more effectively.

Various studies have examined the effectiveness of experimental methods and problem-based learning separately in improving science learning outcomes [30], [31]. However, research specifically exploring the combination of experimental methods and problem-based learning approaches in the digestive system is relatively limited. Most previous studies have focused more on cognitive learning outcomes than on science process skills [32], [33]. This situation indicates a research gap that requires further study. Furthermore, the needs of 21st-century learning demand learning strategies that comprehensively develop scientific skills.

A gap analysis shows that there is still little research examining the effect of integrating experimental and problem-based learning methods on students' science process skills in the concept of the digestive system. The novelty of this research lies in the specific application of the combination of these two learning strategies to measure the strengthening of science process skills. This research is important because it provides an alternative learning model that can address the need to develop students' scientific competencies in the modern era. The urgency of this research is further strengthened given the low level of students' science process skills, which remains a challenge in biology learning. Based on this, the main objective of this study is to analyze the effect of the experimental method with a problem-based learning approach on students' science process skills in the concept of the digestive system.

2. RESEARCH METHOD

2.1. Research Design

The research method applied in this study was a quasi-experimental one. This approach was chosen because the research group selection process was not carried out through full randomization. The use of a quasi-experiment allowed the researchers to still test the effects of the treatment under naturally occurring learning conditions in the school environment [34], [35]. The research design used was a pretest-posttest control group design. This design involved two research groups, namely the experimental group and the control group, each receiving a different learning treatment according to the research objectives. Before the treatment was administered, both groups first took a pretest to determine the students' initial abilities. After the entire treatment series was completed, both groups were given a posttest to measure changes in learning outcomes. An overview of the research design is presented in Table 1.

Table 1. Research Design Pretest-Posttest Control Group Design

Group	Pretest	Treatment	Posttest
Experimental	T_1	X_1	T_1
Control	T_2	X_2	T_2

2.2. Population, Sample, and Sampling Techniques

The population is the entire subject targeted in a study. The population in this study includes all students at State Senior High School 1, South Tangerang City. The accessible population in this study is all eleventh-grade students in the Natural Sciences program at the school. The sample is a portion of the population selected to represent the characteristics of the population as a whole. The sample used in this study consisted of some of the eleventh-grade students in the Natural Sciences program at State Senior High School 1, South Tangerang City, with a total of 74 students. The sample was divided into two groups: 33 students from the eleventh-grade Natural Sciences program as the experimental group and 41 students from the eleventh-grade Natural Sciences program as the control group. The sampling technique used was purposive sampling. This technique is carried out by selecting research subjects based on specific considerations and objectives relevant to the research needs [36], [37]. In its implementation, the researcher obtained two class groups that had been designated as research samples. Furthermore, the determination of the classes that acted as the experimental group and the control group was carried out objectively in accordance with the research design that had been prepared.

2.3. Data Collection Techniques

Data collection techniques are the steps taken to obtain information in accordance with the research objectives. In this study, data were collected through two techniques: tests and non-test observation. Both techniques were used to obtain a comprehensive overview of students' science process skills before, during, and after the learning process. Tests were used as measuring tools to determine students' abilities in science process skills. Tests were administered twice: before the treatment was administered as a pre-test and after the treatment was completed as a post-test. The test format used was a descriptive test. The questions given in the pre-test and post-test used the same instrument to maintain measurement consistency, so that changes in results could objectively demonstrate the effect of the treatment. Test data were used to analyze the effect of the application of the experimental method with a problem-based learning approach on students' science process skills in the concept of the digestive system [38], [39].

In addition to tests, this study also used observation techniques as a form of non-test data collection. Observations were conducted through direct observation of classroom learning activities. The type of observation used was non-participatory observation, meaning the observer was not directly involved in the learning activities but merely observed the learning process. Observations were conducted to determine students' science process skills activities during the learning process [40], [41]. Observation data was obtained through observation sheets compiled based on science process skill indicators. In this study, observations were conducted by a biology teacher at State Senior High School 1 in South Tangerang City, acting as an observer.

2.4. Data Analysis Techniques

Research instruments are tools used to measure and obtain data related to the variables being studied. In this study, two types of instruments were used: a science process skills test and a non-test instrument in the form of an observation sheet. Both instruments were designed to obtain data on students' science process skills during the research. The science process skills test was used to measure students' abilities in the experimental and control groups [42], [43]. Questions were developed based on science process skill indicators, including the ability to observe, classify, interpret, predict, ask questions, formulate hypotheses, design experiments, apply concepts, and communicate results. Thus, the developed instrument provides a comprehensive overview of students' mastery of science process skills.

The test used was a written essay-based test. Before validation, eighteen questions were developed. After the validation process, ten questions were deemed suitable for use in the study. Each question was scored based on the level of accuracy of the answer, with a score ranging from zero to four. The instrument grid was systematically structured to ensure the representation of each science process skill indicator across all questions used. The instrument grid can be seen in Table 2.

Table 2. Science Process Skills Instrument Grid

No.	Science Process Skills Aspects	Indicator	Question Number	Number of Questions
1.	Observing	Observing nutritional content in a food sample table	4	1
2.	Grouping	Grouping enzymes according to their location of production and function	5	1

3.	Interpreting observations	Interpreting the human digestive mechanism through images	6	1
4.	Predicting	Predict the effect of villi surface area in the ileum on nutrient absorption.	8	1
5.	Asking questions	Propose a hypothesis about the function of fiber-rich foods.	7	1
6.	Hypothesizing	Propose a hypothesis about the effect of protein on growth.	1	1
7.	Planning experiments	Determine the tools and materials, and explain the steps for testing for formalin content in food.	2	1
8.	Applying concepts	• Explain the function of enzymes • Explain the digestive mechanism of ruminant animals	9, 10	2
9.	Communicating	Converting a table of carbohydrate, protein and fat content in food into a bar chart	3	1
Amount				10

Observation sheets were used to collect data on students' science process skills during the learning process. Students' science process skills activities observed during the learning process included observing, grouping, interpreting observations, predicting, asking questions, hypothesizing, planning experiments, applying concepts, and communicating.

2.5. Data Analysis Techniques

The data analysis in this study was conducted quantitatively to determine the effect of the experimental method with a problem-based learning approach on students' science process skills. Data obtained from test results and observations were analyzed through several stages: calculating ability gains, testing analysis prerequisites, testing hypotheses, and analyzing observational data. These analysis stages were conducted systematically so that the research results could be interpreted objectively. The initial stage of the analysis involved calculating the normal gain to determine the level of improvement in students' science process skills after the treatment [44], [45]. The normal gain value was obtained from the difference between the final and pre-test scores, which was then compared to the ideal score. The calculation results were classified into high, medium, and low categories. This analysis was used to assess the effectiveness of the learning in improving students' science process skills.

Next, a normality test was conducted to determine whether the research data were normally distributed. The normality test used the Liliefors test. The analysis procedure began with calculating raw scores, constructing a frequency distribution, determining the mean, median, mode, standard deviation, and standard score. The obtained values were then compared to the critical values in the Liliefors table. If the calculated value is less than the table value, the data are considered normally distributed. After the data were declared normally distributed, a homogeneity test was conducted to determine the equality of variance between the experimental and control groups [46], [47]. The homogeneity test was conducted using the Fisher exact test by comparing the largest variance to the smallest variance. If the calculated value is smaller than the table value, then the two groups are declared to have homogeneous variances. The results of the homogeneity test serve as the basis for continuing the analysis to the hypothesis testing stage.

Hypothesis testing was conducted using a t-test at a significance level of five percent. This test was used to determine whether or not the experimental method with a problem-based learning approach had an effect on students' science process skills. The test decision was based on a comparison between the calculated and table values. If the calculated value was greater than the table value, then the alternative hypothesis was accepted, indicating an effect of the treatment on the studied variable. In addition to analyzing test data, this study also analyzed observational data to obtain an overview of students' science process skill activity during the learning process. The analysis was conducted by summing all observed science process skill indicators and then converting them into percentages. These percentages were used to describe the level of student engagement in each aspect of science process skills during the learning process. Analysis of science process skill proficiency was also conducted by calculating the percentage achievement of each indicator. This calculation is performed by comparing the total score students obtained on each indicator with the maximum possible score. The results of this analysis provide detailed information on which aspects of science process skills are developing optimally and which aspects still need strengthening through more effective learning strategies.

3. RESULTS AND DISCUSSION

The following is a data analysis that includes statistical analysis prerequisite tests and hypothesis testing.

3.1. Normality Test

In this study, the normality test was obtained using the Liliefors test. The normality test was used to determine whether the data was normally distributed or not at a significance level of $\alpha = 0.05$, with the provision that the data was normally distributed if it met the criteria of $L_{count} < L_{table}$ and the data was not normally distributed if $L_{count} \geq L_{table}$. The results of the normality test calculation for the experimental and control groups can be seen in Table 3.

Table 3. Results of Calculation of Normality Test for Pretest and Posttest of Experimental and Control Groups

Data	Pretest		Posttest	
	Experiment	Control	Experiment	Control
Sample (N)	33	41	33	41
L_{count}	0.144	0.109	0.151	0.130
L_{table}	0.154	0.138	0.154	0.138
Conclusion	Normal	Normal	Normal	Normal

Based on Table 3, the pretest and posttest L counts for both groups are smaller than L_{table} ($L_{count} < L_{table}$), so it can be concluded that the data is normally distributed.

3.2. Homogeneity Test

In this study, to obtain the homogeneity value using the Fisher test at a significance level of $\alpha = 0.05$, with the homogeneity test criteria being that Ho is rejected if $F_{count} > F_{table}$ and H_0 is accepted if $F_{count} < F_{table}$. The results of the homogeneity test calculation for the two groups of research samples can be seen in Table 4.

Table 4. Results of the Pretest and Posttest Homogeneity Test Calculation for the Experimental and Control Groups

Data	Pretest		Posttest	
	Experiment	Control	Experiment	Control
Sample (N)	33	41	33	41
S^2	92.16	80.28	44.22	64.96
F_{count}	1.15		1.47	
F_{table}	1.73		1.76	
Conclusion	Homogen	Homogen	Homogen	Homogen

Based on Table 4, it shows that $F_{count} < F_{table}$ for pretest data obtained F_{count} 1.15 with F_{table} 1.73 (1.15 < 1.73) and for posttest data obtained F_{count} 1.47 with F_{table} 1.76 (1.47 < 1.76) so it can be concluded that the data from both groups have the same or homogeneous variance.

3.3. Hypothesis Testing

From the results of the data analysis prerequisite tests, including the Liliefors test for normality and the Fisher test for homogeneity, it was found that the data were normally distributed and homogeneous. After that, a hypothesis test was conducted to see whether there were differences in the pretest and posttest results of students from the experimental and control groups. The hypothesis test used was a t-test at a significance level of 5% with the following criteria: Ho is accepted if $t_{count} < t_{table}$, and H_0 is rejected if $t_{count} > t_{table}$. The results of the pretest and posttest hypothesis test calculations for both the experimental and control groups can be seen in Table 5.

Table 5. Results of the Pretest and Posttest Hypothesis Test Calculations for the Experimental and Control Groups

Data	Pretest		Posttest	
	Experiment	Control	Experiment	Control
Sample (N)	33	41	33	41
$\bar{x}$	55.61	54.77	81.24	75.11
F_{count}	0.41		3.74	
F_{table}	1.99			
Conclusion	H_0 accepted		H_0 accepted	

Based on Table 5, for the pretest data, $t_{count} < t_{table}$ (0.41 < 1.99) was obtained so that H_0 was accepted. This indicates that there was no significant difference before using the experimental method with a problem-based learning approach on students' science process skills. Meanwhile, for the posttest data, $t_{count} > t_{table}$ (3.74 > 1.99) was obtained so that H_0 was rejected. This indicates that there was a significant difference between the experimental group and the control group, thus it can be concluded that there is an effect of using the experimental method with a problem-based learning approach on science process skills.

The findings of this study indicate that the application of the experimental method integrated with a problem-based learning approach was effective in improving students’ science process skills in the digestive system material. This improvement reflects the importance of active student involvement during the learning process. Through experimental activities, students were encouraged to directly observe biological phenomena, formulate hypotheses, analyze data, and communicate findings scientifically [48], [49]. These learning experiences enabled students to construct knowledge independently rather than merely receiving information passively from the teacher. The problem-based learning approach also created opportunities for students to connect theoretical concepts with real-life situations, thereby strengthening their scientific understanding and reasoning abilities.

The significant difference in posttest scores between the experimental and control groups demonstrates that the integration of experimental methods and problem-based learning provides a more meaningful learning experience than conventional learning approaches. In the experimental group, students not only learned conceptual knowledge about the digestive system but also developed investigative and analytical skills through structured scientific activities [50]. This finding supports the view that science learning becomes more effective when students are actively involved in inquiry-based processes. The combination of experimentation and problem-solving activities helps students develop higher-order thinking skills, especially in interpreting data, identifying relationships between variables, and drawing evidence-based conclusions.

The digestive system topic is highly appropriate for implementing experimental and problem-based learning strategies because the material is closely related to daily life and involves complex biological processes. Experimental activities allowed students to visualize abstract digestive mechanisms more concretely, while problem-based learning encouraged them to explore contextual issues related to nutrition, digestion, and health. As a result, students became more engaged and motivated during the learning process. Increased engagement may also contribute to better retention of concepts and deeper scientific understanding. Therefore, integrating contextual problems into biology experiments can strengthen both conceptual mastery and science process skills simultaneously.

The improvement in science process skills observed in this study is also closely associated with the student-centered learning environment created through the implemented strategy. Students were encouraged to collaborate, discuss, and communicate their findings during experimental activities. Such collaborative learning conditions help students develop communication and critical thinking skills alongside scientific skills. In addition, the teacher’s role shifted from a primary source of information to a facilitator who guided students in investigating and solving problems independently. This learning environment aligns with the demands of 21st-century education, which emphasizes inquiry, collaboration, creativity, and problem-solving abilities.

The results of this study are consistent with previous research indicating that problem-based learning and experimental activities can enhance scientific competence and critical thinking skills. However, this study provides additional evidence regarding the effectiveness of combining both approaches specifically in the digestive system material. The integration of experimental methods and problem-based learning offers a more comprehensive strategy for strengthening science process skills because students are simultaneously involved in scientific investigation and contextual problem solving. This finding contributes to the development of innovative biology learning strategies that can improve the quality of science education in schools.

This research has important implications for biology learning practices in schools. The implementation of problem-based experimental learning can serve as an alternative instructional strategy for teachers to improve students’ science process skills more effectively. By applying this approach, teachers can create a more active, contextual, and inquiry-oriented learning atmosphere. The findings of this study also support the integration of scientific investigation activities into biology curricula to foster students’ scientific literacy and problem-solving abilities. In the long term, strengthening science process skills may help students become more scientifically literate individuals who are capable of making logical decisions based on evidence in everyday life.

Despite the positive findings, this study still has several limitations. First, the research was conducted only in one school with a relatively limited number of participants, which may affect the generalizability of the findings to broader educational contexts. Second, the study focused only on the digestive system material, so the effectiveness of the learning strategy on other biology topics has not yet been examined. Third, the measurement of science process skills was mainly based on essay tests and observations, which may still contain subjective elements in scoring and interpretation. In addition, the duration of the treatment was relatively short, so the long-term impact of the implemented learning strategy on students’ scientific competence could not be fully identified.

4. CONCLUSION

It can be concluded that there is an influence of the application of the experimental method with a problem-based learning approach on students' science process skills in the concept of the digestive system, this is proven by the calculation of the final hypothesis test, namely $t_{count} > t_{table}$ (3.74 > 1.99). Future research is recommended to involve larger and more diverse samples from different schools and educational levels to obtain broader findings. Further studies may also examine the implementation of problem-based experimental learning in other biology topics or integrate digital technologies to support experimental activities. Moreover, longitudinal studies are needed to evaluate the sustainability of science process skill development over time. Through these developments, the implementation of innovative and inquiry-based learning strategies can continue to contribute to improving the quality of science education and students' scientific competence.

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AUTHOR CONTRIBUTIONS

Conceptualization, I.S.W. and N.L.S.; Methodology, I.S.W.; Software, I.S.W.; Validation, I.S.W. and N.L.S.; Formal Analysis, I.S.W.; Investigation, I.S.W.; Resources, N.L.S.; Data Curation, I.S.W.; Writing – Original Draft Preparation, I.S.W.; Writing – Review and Editing, I.S.W. and N.L.S.; Visualization, I.S.W.; Supervision, N.L.S.; Project Administration, N.L.S.; Funding Acquisition, N.L.S.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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