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Effectiveness of Project-Based Learning (PjBL) Model on Students' Learning Outcomes in the Topic of Bacteria

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Abstrak: Capaian belajar kognitif siswa pada pembelajaran Biologi masih rendah pada materi bakteri, mengindikasikan pentingnya penerapan suatu model pembelajaran yang mendorong peningkatan hasil belajar. Salah satu alternatif modelnya yaitu *Project-Based Learning* (PjBL). Tujuan penelitian adalah mengkaji pengaruh model PjBL dengan pra- eksperimen desain *one-group pretest-posttest* terhadap hasil belajar kognitif siswa kelas X SMA Negeri 5 Tuban. Subjek penelitian 34 siswa kelas X-B yang diambil dari keseluruhan populasi siswa kelas X di SMA Negeri 5 Tuban. Pengumpulan data dilakukan melalui tes berupa *pretest* dan *posttest*, selanjutnya dianalisis dengan statistik deskriptif, uji paired sample t-test, serta analisis N-Gain. Temuan penelitian memperlihatkan peningkatan rata-rata nilai siswa dari 65.21 pada saat *pretest* menjadi 86.59 saat *posttest*. Uji t mengkonfirmasikan adanya perbedaan yang bermakna antara skor *pretest* dan *posttest* ($p < 0.001$), perolehan N-gain sebesar 0.61 tergolong pada kategori sedang. Sehingga dapat disimpulkan bahwa penerapan model PjBL berpengaruh signifikan dalam meningkatkan hasil belajar kognitif.
Kata kunci: Efektivitas, PjBL, Hasil Belajar Kognitif, Materi Bakteri

Abstract: Students' relatively poor cognitive achievement in biology, especially on bacteri topic, indicates to a clear need for an instructional approach capable of raising learning outcomes. PjBL represents one such approach. This study set out to examine how applying the PjBL model influences the cognitive achievement of tenth-grade students at Tuban State High School 5. An experimental design using a single-group pretest-posttest format was employed. Thirty-four students from Class X-B were drawn as the sample from the entire tenth-grade population of the school. Learning outcome data were gathered through pretest and posttest instruments, then examined using descriptive statistics, a paired-sample t-test, and N-gain calculations. Findings revealed that students' mean score rise from 65.21 at pretest to 86.59 at posttest. The paired-sample t-test confirmed a statistically significant difference between the two sets of scores ($p < 0.001$), and the N-gain figure of 0.61 was classified as moderate. These results support the conclusion that the Project-Based Learning model exerts a significant positive influence on improving students' cognitive learning outcomes concerning bacteria.
Keywords: Effectiveness, PjBL, Cognitive Learning Outcomes, Bacteria Material

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1. Introduction

Biology instruction in the present era calls for teaching methods that involve students directly in building scientific knowledge, while at the same time cultivating key 21st-century abilities such as critical thinking, creativity, collaboration, and problem-solving [1], [2], [3]. Realizing these competencies requires teachers to design learning experiences that draw students into active participation rather than positioning them as passive recipients of information [4]. Therefore, selecting an appropriate instructional model is crucial for facilitating students' conceptual understanding and improving learning outcomes [5].

Biology education has unique characteristics due to its complex, abstract, and hierarchical concepts [6]. These concepts require students to develop conceptual understanding rather than merely memorize factual information [7]. Conventional biology instruction often limits students' ability to form mental representations of abstract ideas, which leads to weak conceptual comprehension and suboptimal learning outcomes [8]. Consequently, biology instruction requires learning models that actively involve students in constructing knowledge and relating biological concepts to real-life situations, thereby promoting meaningful learning and improving learning outcomes.

Learning outcomes are widely recognized as indicators of students' knowledge, skills, and competencies acquired through a learning process, reflecting the effectiveness of instructional practices [9]. Learning outcomes indicate what students can do after engaging in learning that involves thinking, feeling, and doing [10], [11]. In this study, the learning outcomes examined focused on the cognitive aspect. How well students grasp the subject matter has a direct bearing on cognitive learning outcomes, making it an important factor to take into account [12]. However, in practice, students' cognitive outcomes in biology education remain suboptimal, particularly in the topic of bacteria. This condition is reflected in their limited conceptual understanding and insufficient proficiency in connecting biological content to real-world contexts.

Based on initial observations at SMAN 5 Tuban, there are still students who show suboptimal learning outcomes in biology, particularly in the subject of

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bacteria. One reason is that traditional learning methods do not keep students very interested or engaged in their learning. Furthermore, classroom instruction on bacterial concepts is still predominantly conducted through lectures and question-and-answer sessions. Teachers have rarely implemented Project-Based Learning (PjBL) during classroom instruction or practical activities, and students are seldom assigned authentic projects related to bacterial concepts. Consequently, students have few chances to explore biological phenomena directly, apply scientific ideas to real situations, and build their own understanding, which in turn makes learning about bacteria less effective.

Project-Based Learning (PjBL) serves as an instructional model designed to enhance learners' understanding, while also improving their academic achievement [13], [14] [13], [14]. This learning model focuses on students actively taking part in projects that solve real-world problems by planning, carrying out, and reviewing their work [15], [16], [17]. The typical syntax of PjBL comprises formulating a driving question, planning the project, drawing up a schedule, carrying out and monitoring the project, checking the results, and evaluating the overall learning experience [18]. This series of steps helps students think more deeply, such as solving problems, integrating different pieces of information, and generating answers using scientific ideas [19]. When applied systematically, PjBL can strengthen students' grasp of scientific concepts as well as their cognitive abilities and overall achievement [20].

Bacteria are among the most abstract and complex topics in biology because they encompass cell structure, classification, reproduction, and their roles in everyday life [21]. In high school, this material is often considered difficult by students when it is delivered using learning methods that lack variety [22]. Because of this, students struggle to grasp what bacteria are fully, and their performance in learning about them is not very good [23]. PjBL model is regarded as well-suited to teaching bacteria-related material since it lets students engage with these concepts through contextual project work, such as producing visual media, conducting environmental observations, or examining the role bacteria play in daily life [24]. This method helps students connect ideas from textbooks to real-world events, making it easier for them to imagine and understand complex

concepts [25]. So, PjBL helps students become more involved and makes it easier for them to understand bacterial topics [26].

Prior research by [27] shows that PjBL effectively increases engagement and conceptual understanding in science and STEAM education. Next, a study by [28] reported that PjBL produced a significant positive impact on students' overall achievement in science education. Research [29] also found that integrating PjBL with the STEM approach improved students' scientific competencies. In addition, [30] reported that PjBL helped improve students' science literacy and their ability to work together. In a comparable vein, [31] found that PjBL strengthens both engagement and learning outcomes among biology students. These findings indicate that PjBL has consistently shown positive effects on students' learning outcomes.

Even so, most existing studies have examined PjBL implementation in science education broadly, and research specifically addressing its effectiveness for improving cognitive learning outcomes on bacteria material at the senior-high level is still scarce. Preliminary observation at SMAN 5 Tuban further indicated that PjBL had not yet been applied in a structured way within biology instruction, particularly for bacteria topics, with classroom teaching still dominated by conventional methods that offer few chances for authentic project-based engagement. This study therefore differs not only in its research setting but also in offering empirical evidence on applying PjBL within a context where the model had not previously been used for bacteria content, representing the novelty of this research, which introduces and tests PjBL as an innovative instructional strategy for improving students' cognitive learning outcomes on bacteria.

Building on the discussion above, this research seeks to answer the following question: how effective is the application of the Project-Based Learning (PjBL) model in raising students' cognitive achievement in biology, specifically regarding bacteria? In line with this, the study is directed at assessing how effectively the PjBL model enhances students' cognitive achievement on bacteria-related concepts.

2. Research Method

A one-group pretest-posttest design was adopted for this research, with the analytical framework summarized in Table 1 [32].

Table 1. Design Scheme: One-Group Pretest and Posttest

Class	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2

Information: X = Treatment (implementation of project-based learning models); O_1= Pretest (value before Treatment); and O_2 = Posttest (value after Treatment)

This research design is an experimental process on only one group without a comparison group. The Treatment is given to the group, and the values are compared Pretest and Post-test [33]. The research population consisted of all tenth-grade students at Public Senior High School 5 Tuban, from which 34 students in Class X-B were taken as the sample. Sample selection used a purposive technique based on criteria relevant to the research aims [34]. Class X-B was selected as the research sample based on the relatively homogeneous initial ability levels of the students, as determined by the initial assessment results and the biology teacher's recommendations, as well as time constraints and learning conditions that would allow for optimal research implementation.

This study took place in three parts. In the first part, students took a pretest. The second stage involved implementing the PjBL model as the instructional intervention, followed by the administration of a post-test. The Pretest was administered to learners to assess their prior knowledge before the intervention. The post-tests was administered to evaluate learners' learning outcomes, which used the PjBL learning model. post-test findings were employed to assess the impact of the instructional activities. The PjBL model was carried out in a single class session focused on bacteria, following its typical stages: formulating the essential question, drafting a project plan, building a schedule, monitoring both students and project progress, assessing the resulting outputs, and evaluating the overall learning experience [35]. At each stage, students worked in groups to complete a project involving the creation of a simple poster depicting the structure of a bacterium, followed by providing descriptions of each structural component and its function. Throughout the activity, the teacher acts as a facilitator who guides, monitors project progress, provides feedback, and evaluates project

outcomes and the learning process to ensure that all components of PjBL are carried out systematically.

The data were collected by administering a pretest and a posttest. The instruments used were a written test consisting of 25 multiple-choice questions and a questionnaire consisting of a list of 10 questions that each student had to answer. The questionnaire was distributed after the PjBL model was applied to learning. The questionnaire was used to gather an overall understanding of how students responded to the Project-Based Learning model, including their levels of interest and participation, and their views on the learning process. The questionnaire data were not analyzed quantitatively; instead, they were used descriptively to support the interpretation of cognitive learning outcomes from pretests and post-tests. Prior to its use, the test instrument underwent validity and reliability checks. Validity was established through expert judgment involving two reviewers: a biology education lecturer and a biology teacher. The validation aimed to assess the alignment between the indicators of conceptual understanding, the cognitive domains of the revised Bloom's Taxonomy (C2, C3, and C4), and the multiple-choice items developed. Their review covered the suitability of the content, the construction of the items, the accuracy of the answer options, and the clarity of the wording, confirming that the instrument satisfied construct validity. Following minor revisions based on the experts' recommendations, the instrument was deemed valid and appropriate for use.

The instrument's reliability was assessed using inter-rater reliability, involving two raters: the researcher and a biology teacher. Scoring was conducted using the same answer key for each multiple-choice item. The reliability level was analyzed using the percentage of agreement, defined as the ratio of identical scores to the total number of scores, multiplied by 100% [36]. The analysis produced a 90% agreement rate between the two raters, reflecting consistent scoring and confirming that the instrument was reliable enough to serve as the study's data-collection tool.

Following that, the N-Gain analysis findings were presented in Table 2 to illustrate the extent to which the PjBL learning model affected students' performance in their studies of bacteria.

Table 2. Interpretation of N-Gain Score Percentages

Percentage (%)	Interpretation
< 40	Ineffective
40 – 55	Less effective
56 – 75	Moderately effective
>76	Highly effective [35]

The methods employed for data examination included N-Gain analysis. The effectiveness of PjBL strategy in terms of student learning was assessed using N-Gain analysis. This study was done to see how much better students performed in learning about science, especially regarding bacteria. The way to calculate normal gain, also called N-gain, is like this [37]:

$$\text{N} - \text{gain} = \frac{\text{Skor Posttest} - \text{Skor Pretest}}{\text{Skor Maks} - \text{Skor Posttest}}$$

Table 3. N-Gain Assessment Criteria

Interval	Category
0,70 ≤ n ≤ 1,00	High
0,30 ≤ n ≤ 0,70	Medium
0,00 ≤ n ≤ 0,30	Low [38]

Pretest and post-test scores were subjected to inferential statistical analysis, beginning with a normality test to check the data distribution; data were treated as normally distributed when the significance value (p) was above 0.05 [39]. A paired-sample t-test was then used for hypothesis testing [40]. The hypotheses tested were H_0: no significant mean difference between pretest and post-test, and H_1: a significant mean difference exists. The decision was based on a significance level (α) of 0.05. If the p-value is less than 0.05, then H_0 is rejected and H_1 is accepted, indicating that there is a significant difference in the mean scores between the pre-test and post-test. Conversely, if the p-value is greater than or equal to 0.05, then H_0 is accepted and H_1 is rejected, indicating that there is no significant difference in the mean scores between the two tests.

3. Results and Discussion

This study examined how PjBL was applied in biology instruction on bacteria. It opened with a pretest given to all Class X-B students to gauge their prior knowledge before the intervention began. Subsequently, students participated in learning activities using PjBL through the stages of starting with an essential question, designing a project plan, developing a project schedule, implementing and monitoring the project, assessing the project outcomes, and evaluating the learning experience. Once the intervention concluded, a posttest measuring cognitive learning outcomes was administered, with both the pretest and posttest each consisting of 25 multiple-choice items. Table 4 presents the resulting pretest and posttest scores.

Table 4. Descriptive Statistics for the Pretest and Posttest

Desciption	*Pretest*	*Post-test*
Number of Students	34	34
Average	65,21	86,59
Standart Deviation	6,38	6,76
Varians	40,71	41,76

Table 4's descriptive statistics show a mean pretest score of 65.21 (SD = 6.38) against a mean posttest score of 86.59 (SD = 6.76), pointing to a rise in students' average learning outcomes after PjBL was applied to the bacteria topic. The comparatively small standard deviations further suggest that students' scores were fairly consistent, without wide variation.

Table 5. Results of the Normality Test

Variabel	Statistic	df	Sig. (2-tailed)
Pretest	.940	34	.062
Post-test	.939	34	.057

As shown in Table 5, the Shapiro–Wilk normality test yielded significance values of 0.062 for the pretest and 0.057 for the post-test. Because both figures exceed 0.05, the pretest and post-test data can be regarded as normally distributed, satisfying the normality assumption required before proceeding to the paired-sample t-test.

Table 6. Results of the Paired Samples t-Test

Variabel	Mean Difference	t	df	Sig. (2-tailed)
Pretest–Posttest	-21.38	-24.653	33	<0.001

Table 6 reports a paired-sample t-test with a mean difference of -21.38, a t-value of -24.653, 33 degrees of freedom, and a significance level (Sig. 2-tailed) below 0.001. As this value falls under the 0.05 threshold, a significant difference between pretest and posttest scores is confirmed, leading to the rejection of H_0 in favor of H_1, indicating that the PjBL model significantly improves students' cognitive learning outcomes on bacteria. In other words, applying the PjBL model within the bacteria unit brought about a marked improvement in student achievement.

Table 7. N-gain Test

Pretest	*Posttest*	N-Gain Value	Criteria
65,21	86,59	0,61	Medium

Table 7 shows the mean score climbing from 65.21 at pretest to 86.59 at posttest after PjBL was implemented, classified as moderate, indicates an improvement in students' cognitive learning outcomes following the implementation of PjBL. These learning activities included problem identification, gathering scientific information, discussing findings, creating project products, and reflecting on the learning process. These activities align with the findings of [41], which state that PjBL has a positive impact on biology learning outcomes through active participation. These findings are also supported by [42], which reports that project-based learning improves learning outcomes through authentic, inquiry-oriented experiences. Similarly, [43] shows that PjBL involving real-world tasks supports conceptual understanding, higher-order thinking skills, and retention.

This improvement may also be related to the various activities included in PjBL, such as formulating essential questions, conducting investigations, and presenting project results. These activities encourage students to draw on their prior knowledge, seek out and evaluate scientific information, discuss findings, communicate evidence-based conclusions, and reflect on their learning. Such activities support critical and analytical thinking abilities as well as problem-solving skills [44]. This is consistent with the findings of [45], which report a

significant impact of PjBL on learning outcomes and higher-order thinking skills in biology education.

The characteristics of bacterial concepts make PjBL a relevant learning model for this topic. The structure, reproduction, metabolism, and functions of bacteria can be difficult for students to understand because these aspects cannot be observed directly [46], especially when learning relies heavily on lecture-based methods [47]. Through PjBL, these abstract concepts can be represented through tangible products such as posters, infographics, and reports, thereby helping students connect microscopic concepts to everyday phenomena [48]. Various activities such as investigation, discussion, collaboration, and reflection can further support conceptual understanding and reduce misconceptions [49]. Thus, PjBL offers a contextual and authentic learning experience that is well suited to the characteristics of bacterial concepts [50].

In addition, the medium N-Gain score of 0.61 may be related to differences in student motivation, self-regulation, and engagement during the learning process [51], [52]. Active participation in project-based activities can support students' motivation and learning autonomy by providing opportunities to take an active role in the learning process [53]. A meta-analysis also showed that project-based learning has a positive effect on student motivation, although the magnitude of this effect varies depending on the learning context [54]. Therefore, the medium N-Gain score obtained in this study should be interpreted while taking into account variations in students' learning experiences and levels of participation.

Despite the observed improvements, these findings should be interpreted in light of the limitations of the single-group *pretest-post-test* design, which lacks a control group for direct comparison. The study also involved only one class with a relatively small sample size, thereby limiting the generalizability of the findings. Furthermore, the relatively short implementation period means that the long-term impact on concept retention was not examined. Future research could involve larger samples, include a comparison group, and examine additional outcomes

such as critical thinking, creativity, collaboration, scientific communication, and science literacy.

4. Conclusion

The results of the study show a significant improvement in students' cognitive learning outcomes following the implementation of the *Project-Based Learning* (PjBL) model. The average score increased from 65.21 on the *pretest* to 86.59 on the *posttest*, with an N-Gain score of 0.61, indicating a medium level of improvement. These findings suggest that the implementation of PjBL was associated with improved students' cognitive learning outcomes on the topic of bacteria. Future research should involve larger sample sizes and control groups to further examine the effectiveness of PjBL and investigate its impact on other learning outcomes, such as critical thinking, creativity, collaboration, scientific communication, and science literacy.

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