Quagga
Jurnal Pendidikan dan Biologi

p-ISSN 1907-3089, e-ISSN 2615-5869
Vol 18, No. 1, 2026, pp 83 - 89
Available online https://journal.fkip.uniku.ac.id/quagga
DOI: 10.25134/quagga.v18i1.484

Effect of Brain-Based Learning on Students' Conceptual Understanding of Plant Tissues

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APA Citation: Medina, Z. S. N., Ratnsari, J., & Setiono. (2026). Effect of Brain-Based Learning on Students' Conceptual Understanding of Plant Tissues. *Quagga: Journal of Education and Biology*, 18(1), 83-89. DOI: 10.25134/quagga.v18i1.484.

Received: 24-12-2025 Accepted: 12-01-2025 Published: 07-01-2026

Abstract: *Understanding plant tissue structure is a fundamental yet challenging topic in biology learning due to its abstract and microscopic characteristics. Innovative and contextual learning models are needed to improve students' cognitive learning outcomes. This study employed a quantitative approach using a quasi-experimental method with a non-equivalent control group design. The participants were 44 eleventh-grade students from a public senior high school in Sukabumi, divided into an experimental group taught using the Brain-Based Learning (BBL) model with local plants and a control group taught using the Discovery Learning model. Data were collected through pre-tests and post-tests and analyzed using N-Gain analysis and an independent sample t-test. The results showed that the experimental group achieved a higher average N-Gain score (0.6748, medium-high category) compared to the control group (0.3790, medium category). The independent sample t-test indicated a statistically significant difference between the two groups ($p < 0.05$), demonstrating the effectiveness of the BBL model in improving students' cognitive learning outcomes. The integration of local plants as contextual learning media within the BBL framework supports students' conceptual understanding based on Bloom's Taxonomy, particularly in interpreting, summarizing, and explaining plant tissue concepts. The Brain-Based Learning model is an effective alternative approach for enhancing cognitive learning outcomes in biology, especially for complex conceptual materials such as plant tissue structure.*

Keywords: *Brain-Based Learning, cognitive learning outcomes, plant tissue structure, conceptual understanding, Discovery Learning.*

1. INTRODUCTION

Understanding scientific concepts is a crucial component of biology learning, particularly in topics that involve abstract and microscopic structures such as plant tissue organization. Effective biology instruction should not only transmit factual knowledge but also support students' cognitive processes in constructing meaningful conceptual understanding. However, many students experience difficulties in comprehending complex biological structures due to limited contextualization and insufficient cognitive engagement during the learning process. (Sridana et al., 2018; Faiz & Kurniawaty, 2020).

In the Indonesian educational context, the implementation of the Merdeka Curriculum emphasizes student-centered and contextual learning approaches that encourage conceptual understanding rather than rote memorization (Kemendikbud, 2022). Nevertheless, international assessments such as PISA 2022 reveal that Indonesian students' scientific literacy remains relatively low, particularly in tasks requiring conceptual reasoning and application. This condition indicates persistent challenges in

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students' ability to understand and connect scientific concepts with real-world phenomena, especially in biology learning. According to the results of the 2022 Program for International Student Assessment (PISA), Indonesia ranks 68th with scores of 379 in mathematics, 398 in science, and 371 in reading. These low scores reflect a lack of understanding of scientific concepts, where students are not yet able to connect what they have learned with real-life applications (Riyanti, 2021).

One biology topic that consistently poses conceptual difficulties for students is plant tissue structure. This material requires students to understand microscopic structures, classify tissue types, and relate structure to biological function. Previous studies have reported high levels of misconceptions among students regarding plant tissue concepts, including meristematic, epidermal, vascular, and supporting tissues Sundari et al. (2018). These misconceptions are often caused by abstract instructional methods, limited visualization, and learning activities that do not optimally support students' cognitive processing.

In addition, research by Setiono et al., (2017) revealed that the cognitive ability of biology student-teachers in plant anatomy practical work still needs improvement. With an average score of 68.10, this achievement falls below the expected passing standard of 75. This indicates the importance of effective learning designs to improve cognitive learning outcomes, particularly in complex materials such as plant tissue structure.

Several instructional models, such as Discovery Learning, have been applied to improve students' cognitive learning outcomes in plant tissue topics. Research by Dukomalamo et al. (2018) demonstrated that Discovery Learning can enhance students' cognitive achievement. However, this model still requires strong abstract reasoning skills and may not sufficiently accommodate students who struggle with conceptual visualization and information integration. Therefore, alternative learning approaches that align more closely with how the human brain processes information are needed.

Brain-Based Learning (BBL) is an instructional model grounded in cognitive psychology and neuroscience principles, emphasizing how the brain naturally learns through meaningful experiences, emotional engagement, and multisensory input (Mastoni et al., 2019; Lagoudakis et al., 2024). BBL promotes relaxed alertness, active processing, and the integration of prior knowledge, which are essential for conceptual understanding of complex biological material. By engaging students cognitively and emotionally, BBL supports deeper information processing and long-term retention (Jensen, 2008; Tokuhama-Espinosa, 2014; Caine & Caine, 2016; Lagoudakis et al., 2024; Zadina, 2015)

Although previous studies have reported the positive effects of Brain-Based Learning on students' cognitive achievement and conceptual understanding, empirical evidence regarding its application to plant tissue structure learning remains limited. More importantly, existing studies rarely analyze learning outcomes using specific indicators of the revised Bloom's Taxonomy, which provide a more fine-grained description of students' conceptual processing levels (interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining).

Therefore, this study explicitly positions its contribution in two aspects: (1) investigating the effectiveness of Brain-Based Learning integrated with local plant-based contextual media in teaching plant tissue structure, and (2) systematically examining students' cognitive improvement based on the revised Bloom's Taxonomy indicators. By doing so, this research extends previous findings that mostly focused on general achievement scores, and offers a more detailed cognitive profile of how Brain-Based Learning facilitates conceptual understanding in biology learning (Anderson & Krathwohl, 2001; Mayer, 2017; Hattie, 2012; Duman, 2018).

2. RESEARCH METHOD

Research Design

This study employed a quantitative approach using a quasi-experimental method with a non-equivalent control group design. This design was selected because the participants were assigned to intact classes without randomization, which is common in educational research settings. The study involved two groups: an experimental group taught using the Brain-Based Learning (BBL) model and a control group taught using the

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Discovery Learning model. Bloom's Taxonomy by Anderson & Krathwohl (2001), which includes seven indicators: interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.

Population and Sampling Technique

The population of this study consisted of all eleventh-grade students at a public senior high school in Sukabumi during the 2024/2025 academic year. The sampling technique used was purposive sampling, in which two classes with relatively similar academic characteristics and learning backgrounds were intentionally selected based on recommendations from the biology teacher and school administration.

One class was assigned as the experimental group, and the other as the control group, with a total sample size of 44 students. This technique was chosen to ensure comparable learning conditions between the two groups while maintaining the natural classroom setting.

Research Instruments

The instruments used in this study included a cognitive learning outcomes test and a student response questionnaire. The cognitive test consisted of 14 essay-type questions related to plant tissue structure, designed based on the conceptual understanding indicators of the revised Bloom's Taxonomy by Anderson and Krathwohl (2001), namely interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining. The student response questionnaire employed a four-point Likert scale ranging from strongly agree to strongly disagree to measure students' perceptions of the learning process using the BBL model.

Validity and Reliability of Instruments

Instrument reliability was examined through a pilot test involving students with similar characteristics outside the research sample. The internal consistency of the cognitive learning outcomes test was analyzed using Cronbach's Alpha and yielded a coefficient, indicating good reliability (α = 0.81). The student response questionnaire also demonstrated satisfactory reliability with a Cronbach's Alpha value.

Content validity was evaluated through expert judgment by specialists in biology education and educational measurement. Each item was rated using a four-point relevance scale, and the Content Validity Index (CVI) was calculated. The overall CVI value reached indicating that the instrument had high content validity and was appropriate for measuring students' conceptual understanding of plant tissue structure.

Implementation of the Brain-Based Learning Model

The Brain-Based Learning model was implemented operationally through several structured stages adapted from brain-based learning principles, including pre-exposure, preparation, acquisition, elaboration, and evaluation. The learning intervention was conducted over four instructional sessions, each lasting 90 minutes.

During the pre-exposure and preparation stages, students were introduced to learning objectives and stimulated through contextual questions related to plant tissues found in their surrounding environment. In the acquisition stage, students engaged in direct observation and exploration of local plants available in the school environment. These plants were used as concrete learning media to help students visualize plant tissue structures that are typically abstract and microscopic.

In the elaboration stage, students worked collaboratively in small groups to analyze plant tissue structures, compare different plant samples, and discuss the relationships between tissue structure and function. The teacher acted as a facilitator, guiding discussions and reinforcing key concepts. Finally, in the evaluation stage, students reflected on their learning experiences and completed formative assessments to measure their conceptual understanding.

The control group received instruction using the Discovery Learning model following the standard stages of stimulation, problem identification, data collection, data processing, verification, and generalization, without the use of local plant-based contextual learning.

Data Collection and Analysis

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Data were collected through pre-tests and post-tests administered to both groups before and after the learning intervention. The improvement in students' cognitive learning outcomes was analyzed using N-Gain analysis. To determine the significance of differences between the experimental and control groups, the data were further analyzed using an independent sample t-test after meeting assumptions of normality and homogeneity. Prior to the learning intervention, a pre-test was administered to both groups to examine the initial equivalence of students' cognitive abilities. An independent samples t-test indicated no statistically significant difference between the two groups at the beginning of the study ($p > 0.05$), suggesting that both groups were comparable in terms of initial cognitive ability.

The normality of the pre-test and post-test scores was examined using the Shapiro–Wilk test. The results demonstrated that the data were normally distributed for both groups. Homogeneity of variance was tested using Levene's test and and indicated heterogeneous data ($p < 0.05$), suggesting that the groups were not equivalent at the initial condition. Therefore, normalized gain (N-Gain) scores were used in subsequent analyses to control for pretest disparities. Levene's test confirmed homogeneous variances for the N-Gain scores (Sig. = 0.571 > 0.05), therefore the assumption of equal variances was met. Table 1 shows the indicators and sub-indicators used in this study.

Table 1. Concept Understanding

Indicator	No	Sub-indicator
Interpreting	1	Able to understand and interpret the types of plant tissues and their functions in the context of plant tissue structure.
Exemplifying	2	Able to provide concrete examples of local plants that can be used to understand the structure of plant tissues.
Classifying	3	Able to classify types of plant tissues based on their function.
Summarizing	4	Able to summarize information about plant tissues and the relationships between tissue types based on their respective functions.
Inferring	5	Able to deduce the relationship between different plant tissue structures and their application in real life.
Comparing	6	Able to compare the plant tissue structure of different types of local plants based on direct observation.
Explaining	7	Able to explain the process or mechanism that occurs in the structure plant tissues and how those structures support plant function.

(Anderson & Krathwohl, 2001)

The collected data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to describe the average scores and data distribution, as well as to calculate the percentage of student responses for each indicator and sub-indicator of conceptual understanding. Each statement in the questionnaire was analyzed based on the number of students who selected each response option, which was then categorized into percentages in Table 2.

Table 2. Likert Scale Categories

Percentage	Category
80 – 100%	Excellent
61 – 80%	Good
41 – 60%	Good enough
21 – 40%	Less good
0 – 21 %	Very unfavorable

(Sugiyono, 2018)

3. RESULTS AND DISCUSSION

The implementation of the Brain-Based Learning (BBL) model, utilizing local plants in the teaching of plant tissue structure, has a significant impact on improving students' cognitive learning outcomes. Table 3 presents the comparison of students' cognitive learning gains between the experimental and control groups based on the N-Gain analysis. The experimental group achieved a mean N-Gain score of 0.6748 ± 0.12005, categorized as medium–high, whereas the control group obtained a lower mean N-Gain score of 0.3790 ± 0.09047, which falls into the

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medium category. This result indicates that students who learned using the Brain-Based Learning (BBL) model experienced a substantially greater improvement in cognitive learning outcomes than those who learned through the Discovery Learning model (Mastoni et al., 2019; Yudanti, 2019).

To statistically confirm this difference, an independent sample t-test was conducted. The results showed a significant difference between the two groups ($p < 0.05$), indicating that the observed learning gains were not random but were influenced by the learning model applied. Thus, the BBL model demonstrated a statistically significant effect on students' cognitive learning outcomes.

Table 3. N-Gain Data on Cognitive Learning Outcomes

Group	N-Gain ± Std. Deviation	Category
Experiment	0.6748 ± 0.12005	Medium-high
Control	0.3790 ± 0.09047	Medium

Further analysis of students' conceptual understanding across seven cognitive indicators is presented in Table 4. The experimental group consistently outperformed the control group on all indicators, demonstrating the effectiveness of the BBL model across multiple levels of cognitive processing. The highest achievement in the experimental group was observed in the summarizing indicator (75%), followed by exemplifying (71%) and comparing (69%). These results suggest that students were particularly effective at organizing information, connecting concepts to concrete examples, and identifying similarities and differences when engaged in brain-based learning activities.

In contrast, relatively lower scores were observed in the explaining (62%) and classifying (63%) indicators, although these values remained higher than those of the control group. These indicators involve higher levels of cognitive complexity, requiring students to integrate multiple concepts and articulate biological mechanisms, which may explain the lower achievement compared to other indicators.

Table 4. Concept Comprehension Test Results

Indicator	Group	
	Eksperimen	Control
Interpreting	67%	30%
Exemplifying	71%	39%
Classifying	63%	42%
Summarizing	75%	47%
Inferring	65%	32%
Comparing	69%	43%
Explaining	62%	33%

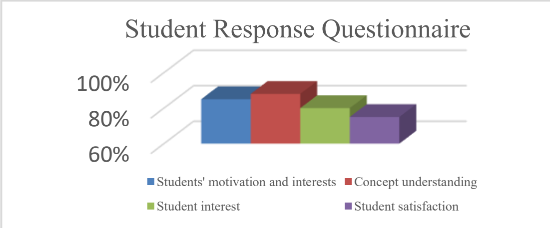

Figure 1. Student response questionnaire

Figure 1, which summarizes the results of the student response questionnaire. The figure shows that 86% of students agreed or strongly agreed that the use of local plants and the Brain-Based Learning approach made learning more engaging, enjoyable, and easier to understand. This positive affective response supports the quantitative findings and indicates that students' emotional readiness and motivation contributed to improved learning outcomes.

Thus, the BBL model not only enhances students' cognitive aspects but also facilitates a more natural, enjoyable, and relevant learning process. This is in line with the findings of (Mastoni et al., 2019), which suggest that a learning environment designed based on brain principles fosters deeper emotional and cognitive engagement among students.

Additional Factors and Study Limitations

Despite the significant effectiveness of the Brain-Based Learning model, several additional factors may have contributed to the observed learning gains. One important factor is the role of the teacher as a facilitator who guided group discussions, provided feedback, and ensured that students remained cognitively engaged throughout the learning process. Differences in students' prior knowledge, learning motivation, and cognitive readiness may also have influenced

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individual learning outcomes, even within the same instructional model.

This study is subject to several limitations. First, the sample size was relatively small and limited to one school, which may restrict the generalizability of the findings. Second, the intervention was conducted over a short period of four instructional sessions, which may not fully capture the long-term impact of Brain-Based Learning on conceptual retention. Third, this study focused exclusively on cognitive outcomes and did not examine affective or psychomotor domains in depth. Future research is therefore recommended to involve larger and more diverse samples, apply longer intervention durations, and explore the effects of Brain-Based Learning on multiple learning domains.

4. CONCLUSION

The findings of this study demonstrate that the implementation of the Brain-Based Learning (BBL) model significantly improves students' cognitive learning outcomes in learning plant tissue structure. The improvement is evidenced by a higher average N-Gain score in the experimental group compared to the control group, as well as superior achievement across all indicators of conceptual understanding. Among these indicators, the summarizing indicator showed the highest level of improvement, indicating that BBL effectively supports students in organizing and integrating biological concepts into coherent knowledge structures.

Furthermore, notable improvements were also observed in the exemplifying, comparing, and interpreting indicators, suggesting that the use of local plant materials and contextual learning activities facilitated deeper conceptual understanding and meaningful learning experiences. These results confirm that learning activities designed in accordance with brain-based principles can enhance both cognitive engagement and conceptual comprehension.

From a practical perspective, the Brain-Based Learning model is highly suitable for biology topics that are abstract and require strong visualization, such as plant tissue structure. For teachers, BBL offers an effective instructional approach that integrates real-life contexts and active learning strategies to improve students' understanding. For curriculum developers, the findings suggest that incorporating brain-based learning principles into biology curricula can support the achievement of higher-order cognitive skills and improve overall learning quality.

5. ACKNOWLEDGEMENTS

The author would like to express gratitude to the Biology Education Program at Universitas Muhammadiyah Sukabumi, as well as to the partner school for granting permission, providing facilities, and offering support throughout the research process. The support from the teachers and students involved in this study has been invaluable in completing this research.

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