Biosaintifika 17 (3) (2025): 442-454 p-ISSN 2085-191X | e-ISSN 2338-7610
Journal of Biology & Biology Education https://journal.unnes.ac.id/nju/index.php/biosaintifika

Quantitative Literacy-based Laboratory Activity Design on the Effect of Color Spectra on Photosynthetic Rate

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Submitted: 2025-07-01. Revised: 2025-09-04. Accepted: 2025-11-07.

Abstract. The Ingenhousz photosynthesis experiment conducted in schools aims to verify the concept of plants producing oxygen. However, opportunities to develop students' quantitative literacy and train science process skills (SPSs) remain limited, as photosynthesis experiments commonly employed in schools are predominantly qualitative. This research aimed to develop an alternative photosynthesis laboratory activity design (LAD) based on an analysis of existing LADs to enhance students' quantitative literacy and SPSs. Using the Research and Development (R&D) method, this research focused on the effect of color spectra on photosynthetic rate—an aspect that presents novelty of this research. The existing LADs were analyzed in terms of relevance, competence, knowledge construction, and practical aspects, resulting in 83.3% (very good), 43.1% (fair), 58.3% (fair), and 55.6% (fair), respectively. The analysis results of these four aspects are the basis for developing the alternative LAD. The alternative LAD was developed and then validated, resulting in a validity value of 0.915, which is categorized as valid. The alternative LAD trial demonstrated that it can collect quantitative data and enhance students' quantitative literacy and SPSs, with the blue light spectrum producing the highest photosynthetic rate at 0.4 ml/g. The quantitative literacy-based LAD fosters data-driven thinking crucial for future scientific inquiry. This supports cultivating more analytically skilled students equipped to face real-world environmental and scientific challenges.

Keywords: Color spectra; experiment design; Ingenhousz experiment; photosynthesis; quantitative literacy

How to Cite: Ningsih, K., Yuniarti, A., Supriatno, B., Faturrahman, M. A., & Haruno, M. (2025). Quantitative Literacy-based Laboratory Activity Design on the Effect of Color Spectra on Photosynthetic Rate. *Biosaintifika: Journal of Biology & Biology Education, 17(3)*, 442-454.

DOI: http://dx.doi.org/10.15294/biosaintifika.v17i3.23949

INTRODUCTION

Biology is increasingly quantitative (Milligan & Rohde, 2024), requiring students to master biological concepts and quantitative literacy—competencies essential for academic success and future careers. In Indonesia, students' quantitative literacy remains low, likely due to the separation of math and biology instruction and a focus on qualitative learning (Jamil et al., 2024). Related to quantitative literacy, science process skills (SPSs) play a key role in biology learning and can be developed through experiment activities. Experiment-based learning has been proven to improve students' concept mastery (Ulfa et al., 2017), quantitative literacy skills (Khoerunnisa et al., 2020), and SPSs (Wiwin & Kustijono, 2018). However, effective experiments require guidance, usually provided through activity sheets or experiment guides (Hidayati et al., 2019). Therefore, a well-designed laboratory activity design (LAD) is essential for achieving targeted competencies and optimizing learning outcomes.

Photosynthesis is one of the most complex and challenging topics in biology education (Eriksson et al., 2025), with the potential to improve concept mastery, quantitative literacy, and SPSs by data visualization. This topic discusses how plants convert light energy into chemical energy to form starch (Ulfa et al., 2017) and release oxygen (Suryani et al., 2017), with chlorophyll acting as the primary agent in carbon dioxide fixation and carbohydrate formation (Haryuni & Dewi, 2016). The preliminary study of photosynthesis experiments in Pontianak schools identified three main issues: (1) existing LADs emphasize light's role while overlooking factors such as carbon dioxide utilization and glucose production; (2) weak design and inadequate equipment limit quantitative data collection; and (3) they fail to develop students' SPSs effectively. This results in a critical gap—the lack of well-designed LADs integrating quantitative data collection and analysis. The dominant qualitative approach in schools limits students' engagement with quantitative data and the development of SPSs.

Photosynthesis experiments with appropriate activities help students gain knowledge and targeted skills. Thus, a well-defined, specific LAD focused on contextualized SPSs and quantitative literacy is needed (Syahirah et al., 2025). This research aimed to develop an alternative LAD, based on the problems with the existing LADs, to enhance students' quantitative literacy and SPSs on the topic of photosynthesis. The focus of the alternative LAD developed in this research is the effect of color spectra on photosynthetic rate, which has not been explored before. Different light spectra yield varying photosynthetic rates, making them ideal for enhancing students' quantitative literacy and SPSs—highlighting the research's significance. Successful experiments require a well-structured LAD and accessible, well-designed kits to ensure smooth execution and achievement of learning objectives.

This research helps students develop skills to interpret, analyze, and use quantitative data, fostering biological literacy and strong quantitative literacy and SPSs. By using well-designed LADs, students can have the opportunity to gain structured, hands-on experience. This experience deepens their understanding of complex biological processes, such as photosynthesis. Beyond improving conceptual understanding, the alternative LAD enhances education quality, reduces learning gaps in under-resourced schools, and prepares students for higher education and data-driven scientific careers. This research benefits both science and society by fostering critical thinking, promoting evidence-based decision-making, and enabling the effective addressing of complex data challenges. Integrating innovative, research-based LADs into biology education supports the creation of a scientifically literate and socially responsible generation.

METHODS

Research Method

The research method used was Research and Development (R&D). The development model employed in this research is the Borg & Gall model (in Setyowati et al., 2024), which was limited to the fifth stage, namely design revision. This limitation was set because the research focuses on developing the alternative LAD based on the potential and problems analyzed.

Potential and Problems

The potential and problems in this research reveal strengths and challenges in photosynthesis learning, forming the basis to develop an alternative LAD that improves students' quantitative literacy and SPSs. Purposive sampling was used, involving four twelfth-grade biology LADs on the photosynthesis topic. The instrument used is a rubric for assessing the existing LADs, consisting of 4 aspects: relevance, competence, knowledge construction (adapted from Novak & Gowin, 1984), and practicality (Table 1).

Data Collection

Curriculum analysis of the *Merdeka* Curriculum was refined into a learning objectives flow focused on photosynthesis, selected for its suitability for experiment-based learning and relevance to quantitative literacy and SPSs. The content review centered on how different light spectra influence photosynthetic rate. Subsequently, quantitative literacy was framed using the framework proposed by the Association of American Colleges and Universities (AAC&U, 2009), emphasizing interpretation, representation, and analysis. The SPSs were selected based on their relevance to the alternative LAD.

Product Design

The alternative LAD used a modified Ingenhousz kit to measure oxygen bubble volume under different light spectra. A student activity sheet was developed, aligning with selected AAC&U's (2009) quantitative literacy dimensions and only the SPSs considered most relevant to the alternative LAD's intentions. The design was trialed in the Biology Education Laboratory at Tanjungpura University to evaluate its feasibility and potential to enhance students' quantitative literacy and SPSs.

Table 1. Rubric lattice of LAD analysis

Aspect	Indicator	Max. Score
Relevance	Matching activity content with learning outcomes	3
Maximum Score of the Relevance Aspect		3
Competence	Observation skills through experiment activities	3
	Questioning and predicting skills through experiment activities	3
	Planning and conducting investigation skills through experiment activities	3
	Processing, analyzing data, and information skills through experiment activities	3
	Evaluation and reflection skills through experiment activities	3
	Communicating results skills through experiment activities	3
Maximum Score of the Competence Aspect		18
Knowledge construction (Novak & Gowin, 1984)	Focus question	3
	Object or phenomenon	3
	Theories, principles, and concepts	3
	Notes or data transformation	3
	Knowledge claims	3
Maximum Score of the Knowledge Construction Aspect		15
Practicality	Practicality of experiment tools and materials according to school standards	3
	Clarity of experiment tools and materials	3
	Composition of experiment procedures	3
Maximum Score of the Practicality Aspect		9

Design Validation

The alternative LAD proceeded to design validation, where five experts assessed its content validity based on curriculum alignment, integration of quantitative literacy, and inclusion of SPSs. A product design validation sheet was employed as the instrument, consisting of four aspects: content, language, presentation, and graphics. The resulting quantitative data were analyzed using the validity index proposed by Aiken (1985), while qualitative feedback was used to guide design revisions.

Design Revision

The alternative LAD was revised using the comments and suggestions from the validators. The feedback helped fine-tune the design, ensuring it met the necessary pedagogical standards and was ready for further research.

Data Analysis

The data derived from the potential and problems analysis were transformed into numerical values using Formula 1. The numerical values were then classified into the categories shown in Table 2, which was adapted from the categories of experiment design quality by Setyowati et al. (2024).

$$P = \frac{F}{N} \times 100\% \quad \text{...(1)}$$

Description:
P = Value in percentage
F = Total score achieved
N = Maximum score

Table 2. LAD achievement category

Value Interval (%)	Category
81-100	Very good
61-80	Good
41-60	Fair
21-40	Poor
0-20	Very poor

The content validation results of the alternative LAD were analyzed using Aiken's (1985) validity index (Formula 2). The validators in this research consisted of two lecturers from the Biology Education study program at Tanjungpura University and three senior high school biology teachers in Pontianak. According to Aiken (1985), with five validators, a highest score of four, and a 95% confidence level, the minimum validity index is 0.87; values below this are considered invalid. The alternative LAD was trialed to assess its ability to measure color spectra effects on photosynthetic rate and enhance students' quantitative literacy and SPSs.

$$V = \frac{\Sigma s}{n(c-1)} \quad (2)$$

Description:
V = Aiken's validity index
s = Score given by the validator minus the lowest validation score (1)
n = Number of validators
c = Highest validation score

RESULTS AND DISCUSSION

Potential and Problems

Relevance Aspect Analysis

Relevance analysis assessed the alignment of student activity sheets with the *Merdeka* Curriculum learning outcomes. For the senior high school photosynthesis topic, students are expected to understand metabolic processes and protein synthesis, including the factors that affect photosynthesis. As a complex topic involving biochemical reactions and energy conversion, photosynthesis requires an understanding of abstract concepts, such as light absorption and energy transformation. Therefore, effective teaching must help students comprehend these fundamental processes. Photosynthesis requires activities or experiments that reinforce concepts to ensure proper student mastery (Ulfa et al., 2017).

The relevance aspect analysis revealed that the four activity sheets obtained scores of 3, 3, 3, and 1, respectively, yielding an average score of 2.5. This result corresponds to an achievement rate of 83.3%, which falls within the very good category. Analysis of four student activity sheets revealed varying conformity levels with learning objectives. Student activity sheets 1, 2, and 3 show good alignment, effectively reflecting the objective "Observing the effect of light on photosynthesis." These sheets are well-structured and support achieving the intended learning outcomes. Student activity sheet 4 shows a mismatch between its learning objectives and activity content. Its first objective, "To prove that photosynthesis produces oxygen," is not fully supported, as students only observe air bubbles without verifying that they are oxygen. The second objective, "Observing factors influencing photosynthesis," focuses solely on light intensity, limiting scope. This misalignment weakens the sheet's design, hindering students' analytical skill development and the achievement of intended outcomes.

Competence Aspect Analysis

Competence aspect analysis aims to analyze the SPSs students can develop through experiment activities. Experiment activities should help students learn content and develop knowledge-acquisition skills (Setyowati et al., 2024). The results of the competence aspect analysis show that the student activity sheets are in the fair category, with a 43.1% achievement rate (Table 3).

Two key indicators—questioning and predicting skills, and communicating results skills—were completely absent in the analyzed student activity sheets. None allowed students to formulate scientific questions, make predictions, or communicate experiment outcomes. Only four indicators (first, third, fourth, and fifth) appeared in the student activity sheets but were not fully optimized.

The first indicator scored an average of 2. Although student activity sheets include observations, they mainly emphasize counting bubbles in photosynthesis, focusing on confirmation rather than analysis or insight construction. Additionally, the student activity sheets do not promote quantitative interpretation of observation data. Accurate data interpretation in experiments shapes the construction of knowledge (Wiwin & Kustijono, 2018).

Table 3. Competence aspect analysis results

No.	Indicator	Student Activity Sheet				Mean
		1	2	3	4	
1	Observation skills through experiment activities	2	2	2	2	2
2	Questioning and predicting skills through experiment activities	0	0	0	0	0
3	Planning and conducting investigation skills through experiment activities	2	2	2	2	2
4	Processing, analyzing data, and information skills through experiment activities	2	3	3	3	2.75
5	Evaluation and reflection skills through experiment activities	2	0	2	0	1
6	Communicating results skills through experiment activities	0	0	0	0	0
	Total Score					7.75
	Percentage					43.1%

The third indicator scored an average of 2. This indicator can be found in all four student activity sheets, but it is suboptimal. This results from the lack of planning skills, causing the student activity sheets to focus solely on conducting investigations. Planning skills help students understand and explain the investigation procedures, enabling them to design processes that produce answers aligned with the focus question (Idris et al., 2022).

The fourth indicator scored an average of 2.75. Student activity sheet 1 scored lower due to limited instruction: "Compare the number of bubbles in both assembled tools!", which is too superficial to promote deep analysis. These instructions fail to guide students in identifying patterns, causality, or using quantitative data, limiting their data analysis skills. It is essential that students be equipped to critically analyze and evaluate scientific data through representative visualizations (Syahirah et al., 2025).

The fifth indicator scored an average of 1.5. The guidance focused mainly on summarizing results, lacking prompts for critical evaluation or improvement. As a result, students were not supported in developing higher-order thinking or reflection. Reflection is vital in learning, helping students evaluate experiences and gain insights for improvement (Mutlu, 2020).

Knowledge Construction Aspect Analysis

Knowledge construction aspect analysis aims to analyze the process of knowledge construction based on observed objects or phenomena. This analysis draws on the components of Gowin's Vee diagram, part of the metacognitive strategies heuristic by Novak & Gowin (1984). The knowledge construction aspect analysis results show that the student activity sheets are in the fair category, with a 58.3% achievement rate (Table 4).

The first indicator scored an average of 1.5. This is caused by the absence of the focus question in student activity sheets 3 and 4. In line with the Novakian principle, focus questions serve to orient students toward particular phenomena, enabling them to collect relevant data and construct knowledge as a means of demonstrating cognitive understanding (Campbell, 2022). Including such questions before photosynthesis experiments can increase interest, encourage discussion, and help students reflect on their investigations (Münkel-Jiménez et al., 2020).

The second indicator scored an average of 3. This indicates that the main object or phenomenon is optimum and identified in all of the student activity sheets. The object or phenomenon in student activity sheets reflects core concepts, helping students connect new information with prior knowledge. This suggests that students construct knowledge by applying prior understanding to make sense of a new phenomenon (Venkatesan et al., 2017).

The third indicator scored an average of 1. Only student activity sheets 1 and 3 included these elements, but they poorly guided students in analyzing and transforming experimental data. The concepts were limited, depicting photosynthesis only as food production rather than energy transformation. According to the principle of Gowin's Vee diagram—included in the metacognitive strategies heuristic developed by Novak and Gowin—theories, principles, and concepts support understanding and assist students in transforming collected data into meaningful knowledge claims (Kurniasih & Irpan, 2019; Permana & Nuraeni, 2021).

The fourth indicator scored an average of 1.5. While present in all student activity sheets, data interpretation often mismatched the objectives, leading to incomplete or inaccurate concepts. Data transformation is essential for organizing observations into tables, diagrams, or graphs, guiding students to focus on key questions and construct meaningful knowledge (Angra & Gardner, 2017).

Table 4. Knowledge construction aspect analysis

No.	Indicator	Student Activity Sheet				Mean
		1	2	3	4	
1	Focus question	3	3	0	0	1.5
2	Object or phenomenon	3	3	3	3	3
3	Theories, principles, and concepts	2	0	2	0	1
4	Notes or data transformation	1	2	2	1	1.5
5	Knowledge claims	2	2	2	1	1.75
	Total Score					8.75
	Percentage					58.3%

The fifth indicator scored an average of 1.75. While present in all student activity sheets as questions guiding data interpretation, these questions do not encourage students to revise concepts or discover new relationships. Knowledge claims are analyzed through directions or guiding questions, and activity sheets should help students construct knowledge and develop thinking skills for more meaningful learning (Syahirah et al., 2025).

Practicality Aspect Analysis

Practicality aspect analysis aims to analyze the implementation and achievement of laboratory activities in presenting objects or phenomena. The results of the practicality aspect analysis show that the student activity sheets are in the fair category, with a 55.6% achievement rate (Table 5). Figure 1 presents an example of the practicality aspect holistically.

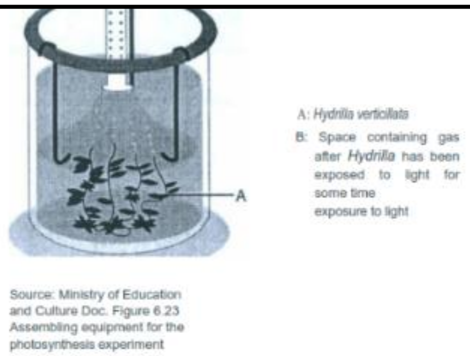
The first indicator scored an average of 3. The student activity sheets list readily available, standard-compliant tools, minimizing logistical issues and supporting smooth classroom integration. Procuring laboratory resources that are up to the standards contributes to the development of human resources (Suseno et al., 2019).

The second indicator scored an average of 1. Even though all of the existing LADs have provided the necessary tools and materials for the experiment, they lack clear instructions on unit indicators. This hinders students from preparing complete tools and materials, disrupting the smooth flow of the experiments (Budiastra et al., 2020).

The third indicator scored an average of 1. Procedures in the student activity sheets are often unclear and poorly structured, leading to errors and failure to observe key phenomena. Clear, detailed experiment procedures help students achieve objectives and emphasize both qualitative and quantitative results (Reynders et al., 2019).

Table 5. Practicality aspect analysis

No.	Indicator	Student Activity Sheet				Mean
		1	2	3	4	
1	Practicality of experiment tools and materials according to school standards	3	3	3	3	3
2	Clarity of experiment tools and materials	1	1	1	1	1
3	Composition of experiment procedures	1	1	1	1	1
	Total Score					5
	Percentage					55.6%


Test) What do you need?

1. Beaker
2. Glass funnel
3. Reaction tube
4. Wire
5. Cutter
6. Thermometer
7. Aquatic plants (Hydrilla sp., Densa sp.)
8. Pond water
9. $NaHCO_3$ solution
10. Halogen lamp

Attempt

1. What are you doing?
   Assemble the equipment as shown in Figure 6.23 (2 sets of equipment).
   a. Insert several healthy aquatic plant branches approximately 10-15 cm long into the glass funnel!
   b. Place the glass funnel into a glass beaker containing water medium with the funnel facing downwards!
   c. Cover the top of the funnel with a test tube that is filled with most of the medium in an inverted position.
2. Place one assembly in a location exposed to direct light and the other assembly in a dark room.
3. Let it sit for 20 minutes! Then, observe whether there are any bubbles inside the test tube!

Figure 1. Experiment with tools, materials, and procedures in student activity sheet 1

Data Collection

Curriculum analysis referred to the *Merdeka* Curriculum learning outcomes, which were elaborated into a learning objectives flow. The topic analysis then focused on photosynthesis, aligning with the outcome "Students can comprehend metabolism and protein synthesis," and was suitable for an experiment-based learning approach. This topic was chosen to foster quantitative literacy through activities such as measuring the volume of oxygen bubbles under different light spectra and analyzing the resulting data. The learning objectives flow was refined into specific goals addressed through experiments designed to enhance quantitative literacy.

The next stage involved reviewing the photosynthesis topic to identify concepts suitable for developing the alternative LAD, particularly the effect of light spectra on photosynthetic rate. The construct of quantitative literacy was defined using the AAC&U's (2009) framework, aligning the alternative LAD with three selected dimensions of quantitative literacy—interpretation, representation, and analysis—based on their relevance. The SPSs, adapted from the basic and integrated SPSs described in Gizaw & Sota (2023), were selected based on their relevance to the alternative LAD. They include the basic SPSs of observation, questioning, predicting, and inferring; and the integrated SPSs of experimenting and interpreting data. Integrating the curriculum requirements, topic content, and frameworks of quantitative literacy and SPSs formed the foundation for product design. This alignment ensured the LAD supported students' conceptual understanding of photosynthesis, quantitative reasoning, and integration of SPSs, reflecting the data collection phase.

Product Design

The alternative LAD aims to improve students' quantitative literacy and SPSs by addressing challenges in measuring bubble counts. It focuses on experiments analyzing the effect of light color spectra on the photosynthetic rate of *Hydrilla verticillata* (L.f.) Royle used a modified Ingenhousz kit composed of glass cups, test tubes, a pipette circuit, a three-way stopcock, a syringe, an infusion hose, a thermometer, a glass rest, and a rubber cup. Plastic sheets in white, yellow, blue, red, and green served as treatments, as illustrated in Figures 2 and 3.

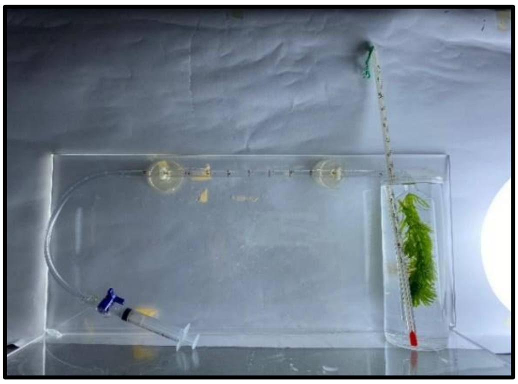
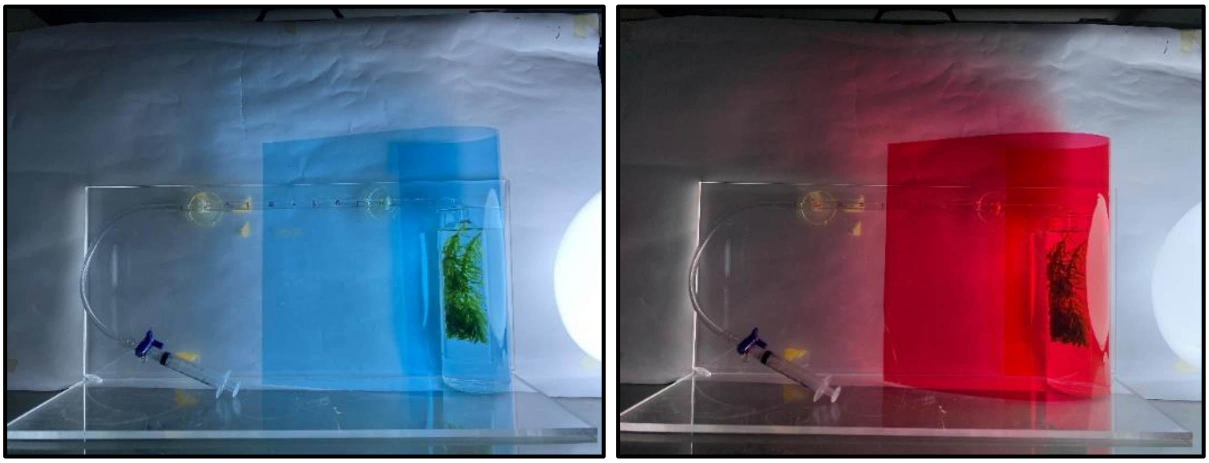


Figure 2. Modified Ingenhousz photosynthesis experiment kit

A glass cup holds the water medium, while a modified test tube connects to a volume pipette. *Hydrilla verticillata* is placed upside down so photosynthetic bubbles enter the pipette for volume measurement. The test tube is connected to an infusion hose, a three-way stopcock, and a syringe to control water flow and collect bubbles. This setup enables easier and more accurate data quantification, addressing previous challenges in data interpretation.



(a) (b)

Figure 3. (a) Blue light spectrum and (b) red light spectrum

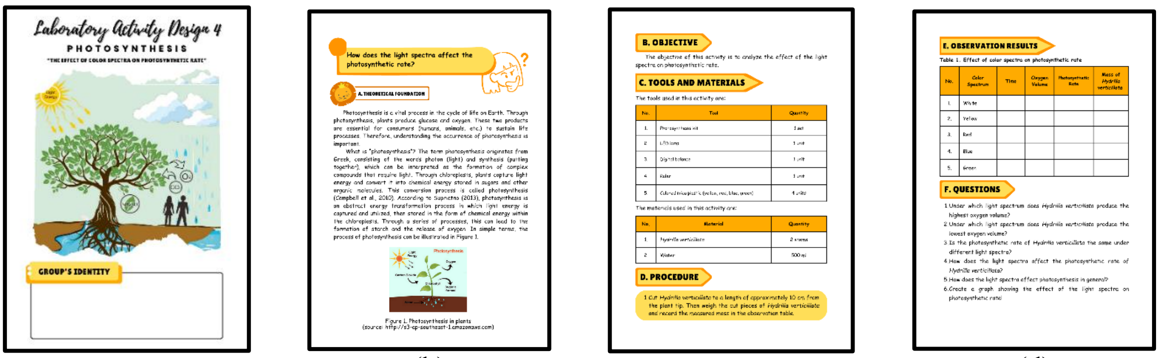
Photosynthesis can be influenced by light intensity, carbon dioxide concentration, temperature, water, leaf traits, and genetics (Sembada et al., 2024). Color spectra also affect photosynthesis indirectly; blue (400-500 nm) and red (600-700 nm) light are most efficient as pigments absorb these wavelengths (Li et al., 2020). Photosynthesis depends on photon quantity, not total light energy (Bhattacharya, 2019). Blue photons have higher energy than red, but both similarly support photosynthesis. Under blue and red color spectra, chlorophyll a and b have high values, resulting in high photosynthetic rates.

A student activity sheet complements the kit. The student activity sheet includes questions guiding students to graph, interpret, and analyze the quantitative data, integrating three AAC&U (2009) quantitative literacy dimensions: interpretation, representation, and analysis. In addition, the developed student activity sheet incorporated indicators of SPSs that were selectively chosen based on their relevance to the alternative LAD. An excerpt of the alternative LAD's student activity sheet is presented in Figure 4. The student activity sheet consists of a cover, a focus question, a theoretical foundation, a purpose, tools and materials, procedures, observation results, questions, and a conclusion. The developed student activity sheet integrates all components reflected in the four aspects analyzed in the earlier "Potential and Problems" stage to support students in mastering quantitative literacy and SPSs. The cover includes the title of the alternative LAD and a section for students to write their identity. The title of the developed student activity sheet is "The Effect of Color Spectra on Photosynthetic Rate."

The focus question in the student activity sheet is "How does the light spectrum affect the photosynthetic rate?", intended to guide students' understanding of the experimental activities and highlight the quantitative nature. The theoretical foundation is comprehensive and relevant to the experiment and intended learning outcomes. It includes an explanation of photosynthesis, the process of photosynthesis, the chemical reactions involved, and the factors influencing the photosynthetic rate. The objective of the experiment is also aligned with the LAD title and the focus question.

The experiment tools and materials listed in the student activity sheet are complemented with unit indicators, supporting the provision of appropriate quantities for the experiment. The experiment procedure is described in great detail, including ten steps written systematically in structured language, specifying the quantity of tools and materials, as well as the estimated time required for each relevant step. Additionally, the procedure features an illustration of the modified experiment kit as a reference model for students to follow, ensuring the experiment is conducted correctly and effectively.

The observation results section is presented in table format for each light spectrum, with data entries including time, oxygen bubble volume, photosynthetic rate, and plant mass observed. Using tables in this section also facilitates students' ability to transform data into graphical form. The questions in the student activity sheet are designed to guide students in claiming knowledge, encouraging them to construct knowledge relevant to the topic and the experiment. The conclusion section serves to confirm the students' ability to perform knowledge claims, thus reinforcing the learning outcomes through the experiment.



(a) (b) (c) (d)

Figure 4. Excerpt of the alternative LAD's student activity sheet: (a) cover, (b) focus question and theoretical foundation, (c) objective, tools and materials, and procedure, and (d) observation results and questions

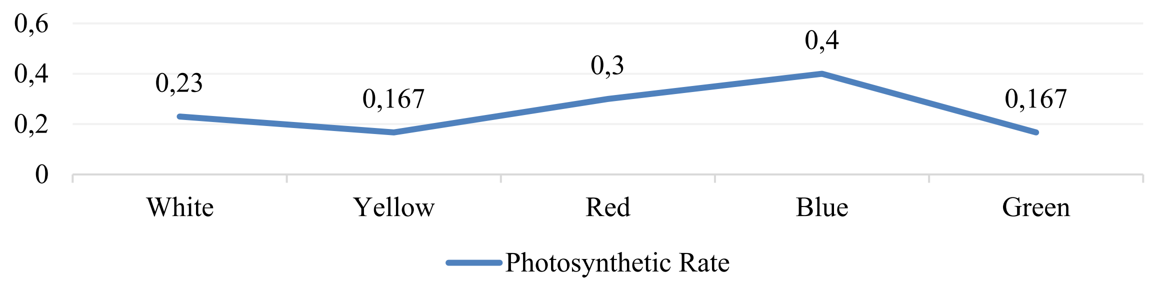


Figure 5. Effect of five color spectra on photosynthetic rate

The developed alternative LAD was trialed at the Biology Education Laboratory of Tanjungpura University to determine its feasibility and success in obtaining data and enhancing students' quantitative literacy and SPSs. The alternative LAD tested five color spectra treatments, with light intensity, carbon dioxide concentration, and temperature controlled to avoid result confusion. The independent variable was color spectra; the dependent variable was photosynthetic rate. Light intensity was kept uniform using an 80-watt lamp, and carbon dioxide levels were stabilized with a buffer solution. The trial of the alternative LAD demonstrated that the modified Ingenhousz kit could generate quantitative data on how light color spectra affect photosynthetic rate, as shown in Figure 5.

Figure 5 shows that the blue light spectrum produces the highest photosynthetic rate (0.4 ml/g). The alternative LAD's student activity sheet also provides several questions related to the representation and interpretation of data or observational facts in the form of tables and graphs, analysis of the effect of the color spectra on the rate of photosynthesis, and other factors that affect the rate of photosynthesis. These questions can direct students to construct knowledge through data or research facts. As implied by the Novakian principle (Campbell, 2022), the questions in the alternative LAD are able to guide students in deriving meaning from observations to answer the focus questions.

The Ingenhousz photosynthesis alternative LAD trial highlights three quantitative literacy skills: interpretation, representation, and analysis. The interpretation component is found in the discussion questions, directing students to interpret the research data by comparing various color spectra to the volume of oxygen produced in the photosynthesis process. The discussion questions are developed referring to the objectives of the experiment so that they can lead to the achievement of a concept listed in the objectives (Kandamby, 2019). The representation component transforms observation data (oxygen bubble volume) into tables and graphs. Presenting data in tables or graphs helps students better understand biological phenomena (Angra & Gardner, 2017). Students are also directed to analyze the existing facts on the effect of the color spectra on the rate of photosynthesis through the questions available on the student activity sheet. The analysis component includes the ability to make decisions and appropriate conclusions based on the quantitative data obtained, consistent with the provisions of AAC&U (2009).

Integrating SPSs into the alternative LAD was realized through the experiment procedure and the student activity sheet. Observation was embedded in the entire experiment as students recorded outcomes to complete the sheet. Questioning and predicting were fostered through focus questions, while experimenting was reflected in the systematic experimental steps. Interpreting data was emphasized by transforming observations into tables and graphs, followed by tasks that required the interpretation of these visual representations. Finally, students' skills in inference were incorporated in the conclusion section, where students assessed their findings and considered their implications. The presence of SPSs in biology learning is essential. Gizaw & Sota (2023) emphasize the importance of incorporating strategies to develop SPSs within teaching materials, classroom activities, and assessments, thereby effectively achieving science education goals. Therefore, integrating the selected SPSs indicators into the alternative LAD can be seen as a means to support the enhancement of students' SPSs.

Design Validation

After the alternative LAD was developed and trialed, proceeding to the design validation stage was deemed feasible. This stage aimed to evaluate the alternative LAD's content validity through assessments by five expert validators. The validation results are shown in Table 6.

Table 6. Alternative LAD validation results

Aspect	Indicator	Aiken's V	Category
Content	Conformity with learning outcomes and learning objectives	0.87	Valid
	Conformity with students' needs	0.93	Valid
	Conformity with the needs of teaching materials	0.93	Valid
	Correctness of topic contents	0.87	Valid
Language	Readability	0.93	Valid
	Clarity of information	0.93	Valid
	Conformity with the Bahasa Indonesia language rules	0.87	Valid
	Precise and efficient use of language	0.87	Valid
Presentation	Clarity of purpose	0.93	Valid
	Order of presentation	0.93	Valid
	Providing motivation	0.93	Valid
	Completeness of information	0.93	Valid
Graphical	Use of font types and sizes	0.93	Valid
	Layout	0.93	Valid
	Images presented	0.93	Valid
	Appearance design	0.93	Valid
Mean		0.915	Valid

The validation results showed that the alternative LAD met the required criteria for content, language, presentation, and graphics, and was deemed valid by experts. Consistent with Hidayati et al. (2019), the validated LAD can support students in generating relevant data and developing targeted skills. However, expert feedback also provided suggestions to enhance its feasibility and classroom readiness.

Design Revision

Design revisions were made based on validator feedback, including clearer procedures and the addition of columns for time and oxygen volume in the observation table. After revision, the alternative LAD was deemed ready for student trials and is expected to serve as a reference for photosynthesis experiments while enhancing students' quantitative literacy and SPSs.

This research addresses the lack of student engagement with numerical data in photosynthesis LADs in Pontianak schools. Therefore, this research presents the novelty as a valid-declared alternative LAD with a specific focus on investigating the effect of different color spectra on photosynthetic rate to enhance students' quantitative literacy and SPSs. Based on the trial, using the alternative LAD can support the observation of measurable differences in photosynthetic rates under five different light spectra and use that data to draw scientifically supported conclusions.

This research supports the broader goal of developing students' ability to interpret and apply quantitative data, fostering biologically literate students with strong quantitative skills. As biology increasingly relies on quantitative methods (Milligan & Rohde, 2024), integrating quantitative literacy into biology education is crucial, as it adapts to a science and society that is increasingly dependent on data-driven decision-making. Implementing well-designed LADs such as the one developed in this research can improve biology education quality in Indonesia, reducing learning disparities in resource-limited schools. Well-designed LADs also deepen students' understanding of complex processes like photosynthesis, enhancing academic performance and preparing students for higher education and data-driven careers. This approach equips students to meet future challenges in a data-oriented workforce.

CONCLUSION

This research produced an alternative LAD designed to enhance students' quantitative literacy and SPSs by focusing on the effect of different light spectra on the photosynthetic rate. The alternative LAD was valid and feasible for trial implementation with students. However, as this research was limited to validation and initial trials, further research is needed to test the alternative LAD's effectiveness in real classroom settings. Future research should evaluate its impact on students' conceptual understanding, quantitative literacy, and SPSs to provide a more comprehensive measure of its educational value.

ACKNOWLEDGMENTS

We would like to express our gratitude to *DIPA PNBP Universitas Tanjungpura 2024* for funding this research.

AUTHOR CONTRIBUTION STATEMENT

KN conceptualization, data curation, funding acquisition, investigation, methodology, project administration, resources, supervision, and writing – original draft. AY conceptualization, data curation, formal analysis, investigation, methodology, validation, and writing – original draft. BS conceptualization, methodology, visualization, and writing – original draft. MAF formal analysis, methodology, visualization, and writing – original draft. MH writing – review & editing.

INFORMED CONSENT STATEMENT

We coordinated with schools and teachers to obtain permission to analyze their LADs as the basis for developing the alternative LAD. All related data are kept confidential to ensure anonymity and comply with research ethics. Participation was voluntary, with no pressure or obligation to provide the LADs. By consenting, schools and teachers agreed that their data would be used solely for research and not disclosed in an identifiable form.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no AI-assisted technologies were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-assisted technologies.

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