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Developing a PBL-Based E-LKPD Integratung Local Temperature Data to Improve Global Warming Conceptual Understanding

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Abstract: *This study aims to develop and examine the effect of using a Problem-Based Learning (PBL)-based E-LKPD integrated with temperature pattern to improve students understanding of global warming. The study employed a Research and Development (R&D) method using the 4D model (define, design, develop, and disseminate), limited to the develop stage. The E-LKPD was implemented with 27 ninth-grade students at a public junior high school in Bengkulu City. Data were collected through observation sheets, student needs questionnaires, interviews, expert validation sheets, student response questionnaires, and conceptual understanding tests in the form of multiple-choice questions (pretest-posttest). Validation by three experts on the aspects of material, media, and language obtained an average score of 99%, indicating that the E-LKPD was highly feasible. The average students score increased from 31.1on pretest to 80.7 on the posttest, with an average N-gain of 0,71, categorized as high. The student responses questionnaire yielded an average of 97%, indicating a very good response. These findings indicate that the developed E-LKPD is highly feasible and support the improvement of students understanding of global warming while receiving very good responses from students..*

Keywords: *E-LKPD; conceptual undertanding; global warming; temperature pattern changes; problem based learning*

INTRODUCTION

The Merdeka Curriculum provides students with opportunities to develop 21st-century concepts and skills through diverse and student-centered learning processes (Hidayatullah et al., 2023). The skills developed cover six aspects: character, critical thinking, creativity, communication, citizenship, and collaboration. One of the subjects relevant for developing these skills is Science.

Science learning (IPA) not only focuses on the mastery of knowledge, but also aims to develop a deep conceptual understanding so that students are able to connect scientific concepts with phenomena occurring in their surroundings (Elcane et al., 2022). Conceptual understanding is a

fundamental ability that helps students grasp abstract ideas, classify objects, and relate them to concrete examples (Pratiwi, 2022).

One of the factors supporting the achievement of conceptual understanding is the use of learning materials that align with the characteristics of 21st-century education. With the advancement of technology, learning materials are no longer limited to printed media but have also evolved into digital resources such as Electronic Student Worksheets (E-LKPD). E-LKPD are digital teaching materials that can enhance students active engagement through interactive, technology-based learning activities (Puspita & Dewi, 2021). To optimize the use of E-LKPD, a student-centered learning model is required, one of which is Problem Based Learning.

Problem Based Learning is a learning model that uses real-world problems as the starting point for integrating new knowledge (Tyas, 2017). This problem-based learning model is closely related to students daily lives and encourages them to think critically, work collaboratively, and actively construct knowledge (Astuti et al., 2024). Through the use of PBL-based E-LKPD, students can address contextual problems in a structured manner, allowing their conceptual understanding to develop optimally (Sari et al., 2022). The PBL syntax consists of five stages: orienting students to the problem, organizing students for learning, guiding investigation, developing and presenting work, and evaluation (Tiara et al., 2024). These stages support active student engagement in understanding concepts through activities such as identifying problems, conducting investigations, presenting findings, and reflecting on the learning process.

The application of the Problem Based Learning model in science learning becomes especially relevant when connected to environmental issues that are close to students lives, such as the phenomenon of global warming. Global warming is one of the real-world contexts that is highly relevant in science education. It refers to the increase in the Earth's average temperature due to human activities, particularly the burning of fossil fuels that produce greenhouse gas emissions such as CO_2 and CH_4 (Pratama & Parinduri, 2019). The Meteorology, Climatology, and Geophysics Agency (BMKG), through the Pulau Baai Climatology Station, recorded that air temperatures in Bengkulu City have shown an increasing trend, averaging 0.026°C per year during the period 1985–2022 (Nita et al., 2024). This local condition provides a strong context to be integrated into the learning of global warming material.

Based on observations, interviews with science teachers, and the distribution of student needs questionnaires conducted at a public junior high school in Bengkulu City, it was found that the teaching materials used are still limited to printed books and worksheets. The use of technology-based learning materials remains very limited, resulting in the learning process being predominantly centered on face-to-face interaction. The results of the student needs questionnaire showed that 96% of students enjoy problem-based learning, and 97% of students require teaching materials that help them understand concepts.

Previous studies have demonstrated the potential of PBL-based digital worksheets in supporting science learning. Develop an electonic student worksheet based on PBL for physics learning and reported that the produst was valid and received very positive responses from teachers and students (Nenggala et al., 2024). Developed a digital student worksheet oriented toward PBL in science learing and demonstrated its fesibility for classroom use (Supriatna et al., 2024). Other recent development studies have focused on digital learning materials for globl warming, including STEM-integrated e-moduls designed to improve students conceptual understanding (Rahmi et al., 2026). Howevwe, these studies generally focus on the development of digital materials, learning models, or global warming content

without specifically integrating local statistical temperature-trend data from Bengkulu City as the empirical basis for problem-solving activities.

Based on these sudies, the research gap lies not in the absence og PBL-based digital learning materials, but in the limited integration of locl temperature-trend evidence into a PBL-based E-LKPD specifically designed for global warming learning and conceptual understanding. This study addresses that gap by using temperature-pattern data from Bengkulu City s an authentic problem context through which students can analyze data, identify patterns, formulate explanations, and connect local temperature changes with the scientific concepts underlying gobal warming. Thus, the novelty of this study lies in the integration of PBL, E-LKPD, and locally derived temperature-pattern data from Bengkulu City within a learning design specifically intended to strengthen students conceptual understanding of global warming.

Therefore, this study aims to develop a PBL-based E-LKPD integrated with temperature-pattern changes for global warming material, determine the feasibility of the developed E-LKPD based on expert validation, examine the improvement of students coceptual understanding after using the developed E-LKPD, determine students responses to the use of the developed E-LKPD. The study is expected to contribute to the development of contextual digital science teaching materials and provide an alternative approach for integrating authentic local environmental data into global warming education.

LITERATURE REVIEW

Teaching Materials

Teaching materials are an essential component and the main guideline in the learning process. In the 21st century, the development of innovative and contextual teaching materials is crucial to improving the quality of education (Siswanto et al., 2025). Relevant teaching materials have a positive impact on learning outcomes and conceptual understanding (Saragih & Dibyantini, 2024). The integration of comprehensive approaches, such as STEM, into teaching materials has also been proven effective in fostering students' critical thinking skills (Panggabean et al., 2024).

The development of teaching materials should therefore consider not only the presentation of scientific content but also the learning activities through which students construct knowledge. Teaching materials that present authentic problems, provide opportunities to investigate evidence, and encourage students to relate concepts to their surroundings are particularly relevant to student-centered science learning. In this regard, digital teaching materials offer opportunities to integrate text, images, data, interactive activities, and assessment into a single learning environment. Thus, the development of digital teaching materials can support the shift from teacher-centered learning toward learning that actively involves students in constructing scientific understanding.

E-LKPD

Electronic Student Worksheets (E-LKPD) are interactive digital teaching materials that contain summarized content and structured assignments. E-LKPDs are more practical because they can be accessed through various technological devices and incorporate engaging multimedia elements. These materials can be accessed via computers, laptops, or smartphones, and include essential activities that students need to complete in order to achieve learning objectives optimally (Puspita & Dewi, 2021).

The development of electronic teaching materials requires attractive digital platforms. The Canva application facilitates visual design that can stimulate students' creativity (Pulungan & Simamora, 2024). Liveworksheet enables the creation of interactive E-LKPDs with automatic correction features (Seputri et al., 2025) In addition, Wordwall is highly effective when

used as an interactive evaluation medium to train critical thinking skills (Panggabean et al., 2024).

Problem Based Learning

PBL is a student-centered learning model that uses authentic or contextual problems as the starting point for learning. Through problems that are relevant to real-life situations, students are encouraged to identify problems, investigate information, construct explanations, discuss possible solutions, and reflect on their learning. This process provides opportunities for students to actively construct knowledge rather than merely receive information from the teacher.

PBL has been widely used in science education because its problem-solving orientation is consistent with the characteristics of scientific iquiry. PBL can support the improvement of scientific literacy and conceptual understanding compared with conventional learning approaches (Sinuraya et al., 2024). The implementation of PBL integrated with Generic Science Skills also significantly enhances learning outcomes and active student engagement (Saragih & Dibyantini, 2024). Therefore, integrating PBL into E-LKPD can provide a structured digital environment in which students encounter problems, conduct investigations, communicate findings, and develop conceptual explanations.

The relationship between PBL and digital learning materials has also received increasing attention. (Nenggala et al., 2024) demonstrated the use of an electronic student worksheet based on PBL to guide students in solving physics problems. In addition, (Angriani et al., 2025) developed a PBL-based e-module and reported its feasibility and practicality for supporting students' critical thinking. Therefore, integrating PBL into E-LKPD can provide a structured digital environment in which students encounter problems, conduct investigations, communicate findings, and develop conceptual explanations.

However, the effectiveness of PBL-based digital materials depends on the relevance of the problems presented to students. Problems that are closely related to students' environments can provide meaningful contexts for learning because students can connect scientific concepts with observable phenomena and available evidence. Consequently, the integration of authentic local environmental data into PBL-based E-LKPD represents an opportunity to strengthen contextual science learning.

Conceptual Understanding

Conceptual understanding can be defined as an individual's ability to master and comprehend an idea or concept thoroughly. A student is considered to have conceptual understanding if they are able to grasp the meaning or significance of a concept being studied (Pratiwi et al., 2022). Conceptual understanding is also reflected when students can explain material in their own words. Thus, conceptual understanding is not just about recalling information, but also includes the ability to connect acquired knowledge to new situations, provide examples, and apply it to solve everyday problems.

In science learning, conceptual understanding is one of the indicators used to assess student achievement of learning objectives (Safitri et al., 2021). Therefore, science learning should not only require students to memorize and know concepts, but also to understand the interconnections between concepts. Research by (Siregar, 2019) revealed that students' conceptual understanding in science subjects is still low, which can hinder their success in learning subsequent material at higher levels.

Conceptual understanding can be identified through several cognitive processes that require students to demonstrate the meaning of a concept. These include explaining a concept in their own words, interpreting information or phenomena, providing appropriate examples, classifying objects or phenomena based on their characteristics, and drawing conclusions

based on available information. These abilities are particularly relevant to science learning because students are expected to use scientific concepts to interpret evidence and explain phenomena rather than merely recall definitions.

Global Warming

Global warming is the increase in the average temperature of the Earth's atmosphere, oceans, and land. It is a global phenomenon triggered primarily by human activities, especially those related to the use of fossil fuels and land-use change. These activities produce increasing amounts of gases in the atmosphere, particularly carbon dioxide (CO_2), through a process known as the greenhouse effect. The term "greenhouse effect" is closely related to global warming. It refers to the rise in Earth's temperature due to heat being trapped in the atmosphere, similar to how a greenhouse traps warmth to maintain the temperature for plants inside. The increase in temperature inside a greenhouse occurs because sunlight reflected by objects inside is blocked by the glass walls, preventing the heat from escaping.

This research aims to develop a Problem Based Learning (PBL)-based E-LKPD that integrates temperature pattern change data from Bengkulu City into global warming material. By incorporating local environmental data as a learning context, this study is expected to contribute to the development of more contextual digital teaching materials, support the implementation of problem-based learning, and enhance students' conceptual understanding of global warming.

METHODS

This study employed the Research and Development (R&D) method (Astuti et al., 2026) using the 4D (four-D) development model proposed by Thiagarajan, which includes the stages of define, design, develop, and disseminate; however, it was limited to the develop stage. The research subjects were ninth-grade students at a public junior high school in Bengkulu City. The study was conducted from November 2025 to May 2026. The data

collection instruments used were observation sheets, teacher needs questionnaires, student needs questinnairs, validation questionnaires, conceptual understanding test items, and student response questionnaires.

The data analysis techniques used in this study included both qualitative and quantitative descriptive analysis. Product validity testing was conducted to determine the feasibility of the developed E-LKPD. Validation was carried out by three validators who evaluated the material, media, and language aspects. The E-LKPD is considered feasible if it achieves a validation score of ≥ 80%. A conceptual understanding test was administered to determine the effectiveness of using the Problem Based Learning-based E-LKPD, based on pretest and posttest data. Pretest and posttest data were analyzed using the N-gain formula to identify improvements in students' conceptual understanding. A student response test was conducted to assess students' perceptions of using the E-LKPD in the learning process. The E-LKPD is considered good if the student response questionnaire yields a score of ≥ 80%.

The implementation of this research began with the define stage of the 4D model. The define stage aims to establish and identify the needs required in the learning process (Hikmawati et al., 2020). During this stage, school observations, analysis of learning outcomes, analysis of teacher needs, analysis of student needs, and scientific data analysis were conducted. Data from school observations, analysis of learning outcomes, and teacher needs analysis were analyzed using qualitative descriptive methods, while data from student needs analysis and scientific data analysis were analyzed using quantitative descriptive methods.

Student needs analysis was conducted to determine students' requirements for learning materials. The questionnaire was constructed using the Guttman scale, which provides definitive answers, namely "Yes" and "No."

Each student's response was scored according to the criteria presented in Table 1.

Table 1. Student Needs Assessment Score

Answer	Score
Yes	1
No	0

The data from the questionnaire were analyzed by calculating the percentage using the following formula:

$$\text{Percentage (\%)} = \frac{\text{Total Validation Score}}{\text{Maximum Score}} \times 100 \quad (1)$$

The resulting percentage was then interpreted according to the criteria in Table 2.

Table 2. Student Needs Criteria

Range	Category
81% < x ≤ 100%	Very good
61% < x ≤ 80%	Good
41% < x ≤ 60%	Fair
21% < x ≤ 40%	Poor
0% < x ≤ 20%	Very poor

Scientific data analysis was conducted to obtain a real picture of the global warming phenomenon occurring in Bengkulu City. The analysis was carried out quantitatively by comparing the minimum, maximum, and average temperatures in Bengkulu City during the period 2021–2025. This analysis aimed to identify temperature changes that occurred during the observation period, so that they could serve as a contextual basis in learning global warming material and be integrated into the E-LKPD.

After completing the define stage, the research proceeded to the design stage. The design stage involves creating the initial product draft based on the results of the previous analyses (Salsabila et al., 2023). In this stage, the researcher designed the E-LKPD, which included determining the format and structure of the teaching material, visual design, preparation of global warming material integrated with temperature pattern changes, development of learning activities according to the Problem Based Learning syntax, as well as preparation of research instruments such as validation sheets, conceptual understanding test items, and student response questionnaires. The outcome of this stage was an initial draft of the E-LKPD, ready for validation and further development in the next stage.

In the develop stage, the E-LKPD draft prepared during the design stage was validated by expert validators. After undergoing revisions, the E-LKPD was implemented in a limited-scale trail to measure its effectiveness in improving following the learning implementation, students were given a response questionnaire. The data from validation, conceptual understanding tests, and student responses were analyzed quantitatively.

Validation needs analysis was carried out to determine the feasibility of the developed E-LKPD (Ulmi, 2018). The validation instrument was constructed using the Guttman scale, which provides definitive answers: "Yes" and "No." Each answer was scored according to the criteria presented in Table 3.

Table 3. Expert Validation Assessment

Answer	Score
Yes	1
No	0

The validation data were analyzed using the following percentage formula:

$$\text{Percentage (\%)} = \frac{\text{Total Validation Score}}{\text{Maximum Score}} \times 100 \quad (2)$$

The resulting percentage was then interpreted according to the criteria in Table 4.

Table 4. Product Feasibility Criteria

Range	Category
81% < x ≤ 100%	Very Feasible
61% < x ≤ 80%	Feasible
41% < x ≤ 60%	Fairly Feasible
21% < x ≤ 40%	Less Feasible
0% < x ≤ 20%	Not Feasible

The analysis of pretest and posttest data was conducted to measure theeffectiveness of the E-LKPD in

improving students' conceptual understanding (Pradnyani et al., 2026). This analysis used the N-gain formula and described the increase in scores from the pretest and posttest administered to students. The N-gain formula is as follows:

$$N\text{-gain} = \frac{\text{Skor Posttest} - \text{Skor Pretest}}{\text{Skor Ideal} - \text{Skor Pretest}} \quad (3)$$

After obtaining the N-gain results, the data were interpreted according to Table 5.

Table 5. N-gain Interpretation

N-gain Value	Category
g > 0,7	High
0,3 ≤ g ≤ 0,7	Medium
g < 0,3	Low

The analysis of the student response questionnaire aimed to determine students' perceptions of the use of the developed E-LKPD. Student responses were assessed using the Guttman scale with definitive answer choices: "Yes" and "No." Each answer was scored according to the criteria shown in Table 6.

Table 6. Student Response Assessment

Answer	Score
Yes	1
No	0

The data from the student response questionnaire were analyzed using the following percentage formula:

$$\text{Percentage (\%)} = \frac{\text{Total Validation Score}}{\text{Maximum Score}} \times 100 \quad (4)$$

The resulting percentage was then interpreted according to the criteria in Table 7.

Table 7. Student Response Criteria

Range	Category
81% < x ≤ 100%	Very good
61% < x ≤ 80%	Good
41% < x ≤ 60%	Fair
21% < x ≤ 40%	Poor
0% < x ≤ 20%	Very poor

RESULT AND DISCUSSION

1. Define Stage

In this stage, five types of data analysis were conducted: school observation, analysis of learning outcomes, teacher needs analysis, student needs analysis, and scientific data analysis. The results of observations at a public junior high school in Bengkulu City indicated that the science learning process is still dominated by conventional methods, with teaching materials that do not yet relate science concepts to students' daily lives or their surrounding environment. This condition highlights the need for the development of more contextual teaching materials to help students understand the material more effectively.

The learning outcomes for the global warming topic require students to be able to design efforts to prevent and address pollution and climate change. These learning outcomes serve as a reference for formulating learning objectives, which include students' abilities to understand the concept of global warming, analyze its causes and solutions, and present projects related to prevention and mitigation efforts. These objectives then become the foundation for developing the material, learning activities, and assessments included in the E-LKPD, ensuring that all components of the learning process are aligned with the expected learning outcomes.

Based on interviews with two science teachers, the use of worksheets (LKS) in the learning process is still limited to only a few topics, resulting in students needing additional learning resources. The use of technology-based teaching materials in the learning process has not been optimal, so it has not fully supported interactive and student-centered learning. The dominant teaching method used by teachers is group discussion. However, in practice, not all students demonstrate the same level of participation. Some students tend to be passive and rely more on their active peers during group discussions. Therefore, there is a need for more engaging and contextual teaching materials, supported by learning approaches that can enhance active student involvement.

The results of the student needs questionnaire showed that 96% of students enjoy problem-based learning, 73% feel actively involved in the learning process, and 97% require teaching materials that help them understand the material more easily and clearly. These results indicate that students support the development of a Problem Based Learning (PBL)-based E-LKPD integrated with temperature pattern changes as supplementary teaching material in science learning.

Previous research also supports the use of PBL-based electronic worksheets to facilitate conceptual understanding. Developed a PBL-based E-LKPD and reported that the product was feasible for learning and showed potential to facilitate students' conceptual understanding (Ramadani & Isnaeni, 2022). In the context of global warming, (Novia & Asrizal, 2023) also reported that an E-student worksheet integrated with PBL on climate change and global warming supported students' conceptual understanding and communication skills.

The scientific data analysis was conducted using monthly air temperature data for Bengkulu City from January 2021 to December 2025, sourced from the BMKG Climatology Station Class 1 Bengkulu. The monthly air temperature data can be seen in Table 8.

Table 8. Air Temperature Data from January 2021 to December 2025

Year	Air Temperature Data (°C)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2021	26,8	27,1	26,9	27,2	27,7	26,9	27	26,7	26,9	26,7	27	27,1
2022	27,1	26,9	27,1	27,3	27,4	26,2	26,8	26,7	26,4	27,1	26,3	26,4
2023	26,3	26,8	27,1	27,4	28,4	27,7	27,2	27,3	26,3	27,1	27,2	27,6
2024	27,5	27,7	27,7	28	28,4	27,8	27,6	27,7	27,7	28	27,2	26,9
2025	26,9	27,1	27,3	27,2	27,9	27,4	27,1	26,8	26,9	27,3	26,7	26,9
Average	26,92	27,12	27,22	27,42	27,96	27,2	27,14	27,04	26,84	27,24	26,88	26,98

Table 8 shows that air temperature in Bengkulu City during the observation period fluctuated with an upward trend. The highest temperatures were recorded in May each year, with the maximum temperature reaching 28.4°C, while the lowest temperature occurred in June 2022 at 26.2°C, resulting in a difference of 2.2°C between the highest and lowest temperatures. This finding is consistent with research by (Ambi et al., 2020) which states that surface air temperature increases in several regions of Indonesia have ranged from 0.0005 to 1.18°C.

The increase in air temperature, which reaches its peak in May, is thought to be related to the climatological conditions of Bengkulu City. May is a transitional period between seasons, commonly referred to as the "pancaroba" season, which is generally characterized by reduced cloud cover, resulting in increased solar radiation reaching the Earth's surface. According to the BMKG, during this transitional period, the weather is generally clearer from morning to midday, allowing for more intense surface heating and consequently higher air temperatures.

This condition is also supported by information from the BMKG Pulau Baai Climatology Station in Bengkulu in 2025, which stated that the hot temperatures in Bengkulu City are caused by high evaporation rates due to the substantial accumulation of solar energy received by the Earth's surface. Reduced cloud cover allows solar radiation to reach the surface more optimally, there by increasing the amount of heat energy stored at the surface. This energy accumulation leads to a more intense warming process, ultimately raising air temperatures in Bengkulu City. To observe the pattern of temperature changes during the observation period, an analysis of minimum, maximum, and average annualtemperatures was conducted, as presented in Figure 1

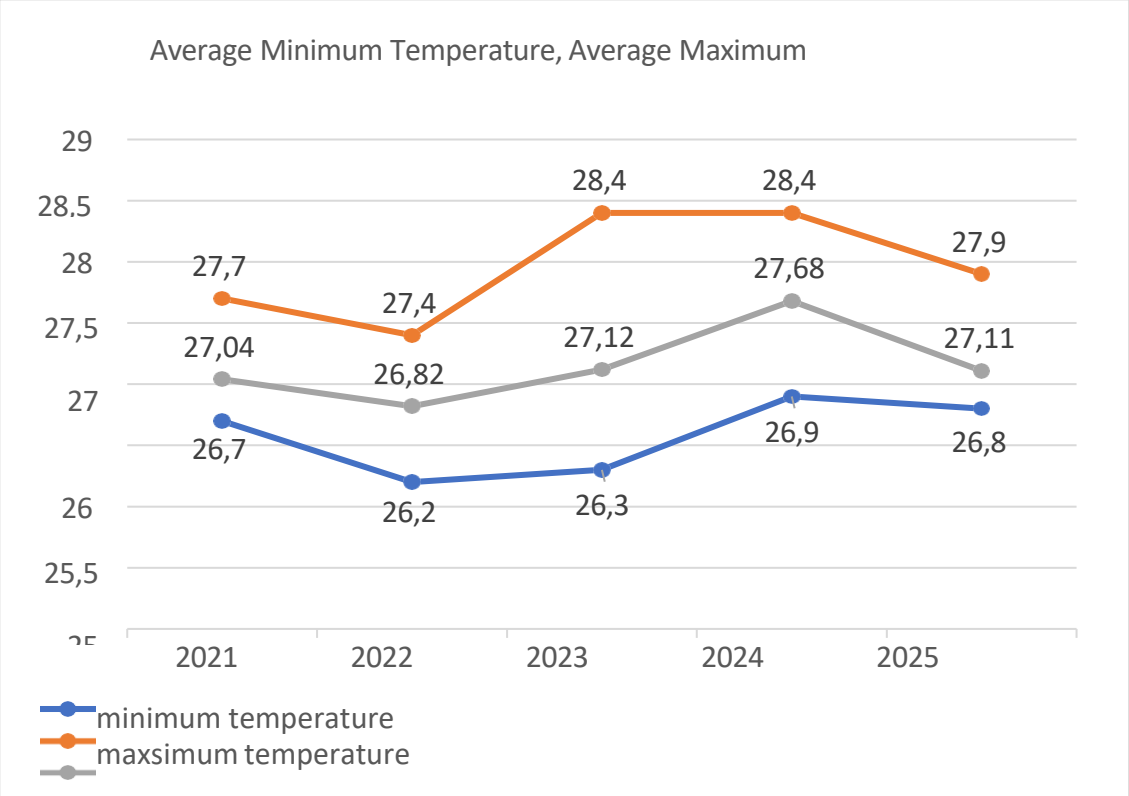


Figure 1. Graph of Minimum, Maximum, and Average Air Temperature Analysis

Based on Figure 1, the annual average air temperature in Bengkulu City varied during the observation period. The lowest annual average was recorded in 2022 at 26.82 °C, followed by 27.12 °C in 2023 and 27.68 °C in 2024. Therefore, the annual average temperature increased by 0.86 °C between 2022 and 2024. In 2025, the annual average decreased slightly to 27.11 °C but remained higher than the values recorded in 2021 and 2022.

These changes in temperature patterns have tangible ecological and social impacts, including disruptions to coastal ecosystems and the potential for altered upwelling, which affects fisheries productivity, decreased income for small-scale fishermen due to unpredictable climate changes (Silaban et al., 2025), as well as increased health risks and reduced thermal comfort for the people of Bengkulu City.

This pattern illustrates an important point for science learning: environmental data may fluctuate from year to year while still showing a particular pattern over a longer observation period. Presenting such data in the E-LKPD allows students to practice interpreting scientific evidence rather than receiving the concept of global warming only through textual explanations. This approach is consistent with contextual science learning, in which scientific concepts are connected to phenomena and resources available in students' surroundings.

The local temperature data were subsequently integrated into the E-LKPD as a real-world problem context. Through this integration, students were encouraged to analyze temperature data, identify patterns, investigate the greenhouse effect, and formulate actions related to global warming mitigation. Thus, the temperature data functioned not merely as supplementary information but as an entry point for implementing the PBL stages.

2. Design Stage

The design stage focused on developing an E-LKPD on global warming that integrates local temperature-pattern data from Bengkulu City and follows the syntax of Problem-Based Learning. Global warming was selected because the topic is closely related to environmental phenomena encountered in students' daily lives and requires students to understand relationships between scientific concepts and environmental problems.

The E-LKPD was designed as supplementary teaching material for teachers and students. Its activities were structured to provide students with opportunities to identify problems, analyze authentic data, conduct investigations, collaborate with peers, and formulate solutions. The initial layout of the E-LKPD is presented in Figure 2

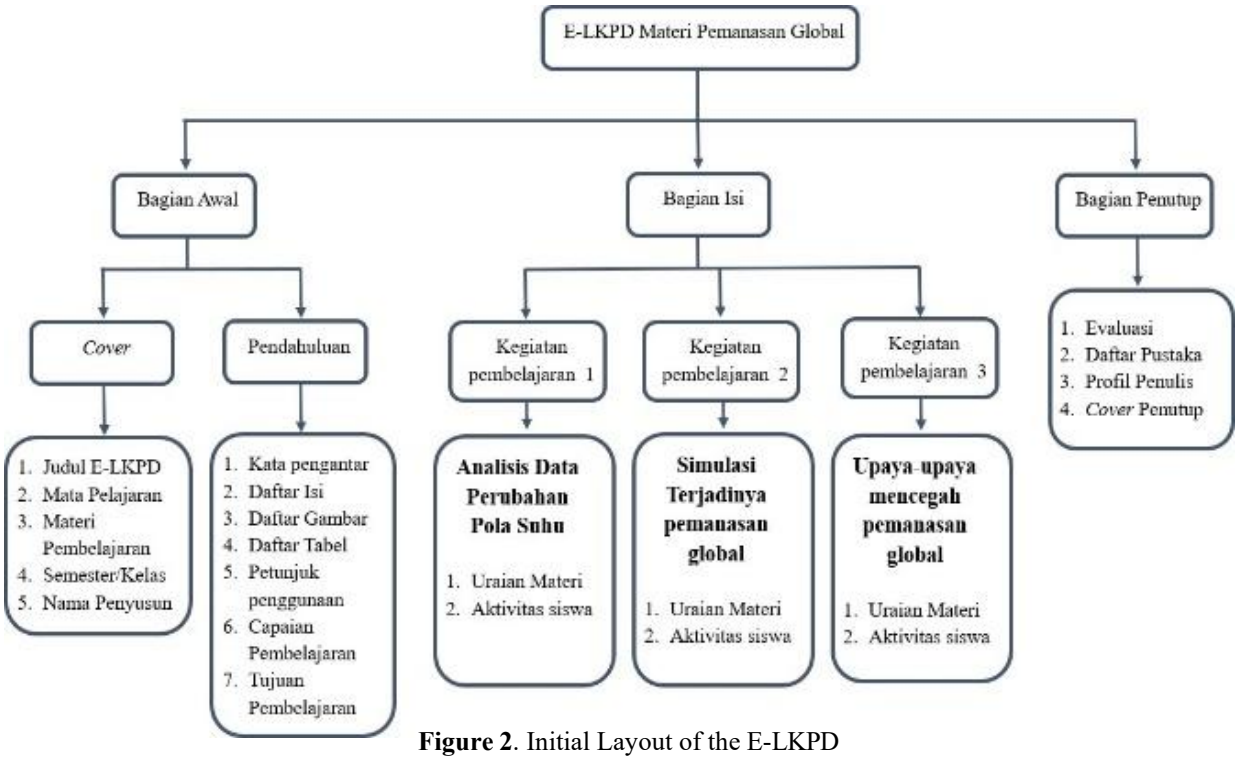


Figure 2. Initial Layout of the E-LKPD

The learning activities were organized according to the five stages of PBL. First, in the orientation to the problem stage, students were introduced to the phenomenon of changes in air temperature in Bengkulu City. This stage was intended to activate students' prior knowledge and encourage them to formulate questions related to the phenomenon.

Second, in the organizing students stage, students were divided into groups of five to six members and directed to analyze monthly air temperature data from 2021 to 2025. The use of local data provided students with an authentic context for interpreting scientific information.

Third, during the guiding investigation stage, students used the PhET Greenhouse Effect simulation to investigate the relationship between greenhouse gases and the warming process. The use of simulation allowed students to visualize scientific processes that cannot be directly observed in the classroom. A review of research on PhET simulations reported that such simulations can support students' conceptual understanding when integrated into active learning environments.

Fourth, in the presenting work stage, students developed and presented posters containing efforts to prevent or mitigate global warming. This activity required students to transform the results of their investigation into a proposed solution and communicate it to others.

Finally, in the evaluation stage, students individually completed evaluation questions to assess their understanding of the concepts discussed during the learning process.

The sequence of activities therefore reflects the characteristics of PBL, in which students are exposed to meaningful problems, investigate information, collaborate with peers, and construct solutions. Previous research on global warming has also reported that PBL can support science learning by engaging students in problem-solving activities related to environmental issues.

3. Development Stage

The development stage was conducted to determine the feasibility of the E-LKPD through expert validation. The product was evaluated in terms of media, material, and language aspects. Suggestions provided by the validators were used to revise the product before the limited-scale trial. The validation results are presented in Table 9.

Table 9. Product Validation Results

Aspek	Rata-Rata	Kriteria
Media	98%	Very Feasible
Material	100%	Very Feasible
Language	100%	Very Feasible
Average	**99%**	**Very Feasible**

Based on Table 9, the overall average validation result is 99%, which falls into the "very feasible" category. This indicates that the developed E-LKPD has met the feasibility standards in terms of visual appearance, material suitability, learning model, and language use. This finding is consistent with (Sari & Purwaningsih, 2023) , who stated that a Problem Based Learning-based E-LKPD is considered feasible if it receives a “very good” rating in all aspects of feasibility. Product revisions were still made despite the validation results being categorized as very feasible. Revisions included improvements to layout, typography, term consistency, and clarity of instructions. Overall, these results

show that the developed E-LKPD meets the feasibility criteria for media, material, and language aspects, making it suitable for further limited-scale trials. The revised and validated E-LKPD can be accessed by scanning the QR Code in Figure 3.

Figure 3. E-LKPD

Next, a limited-scale trial was conducted over three meetings using the Problem Based Learning model. The first meeting focused on the pretest, problem orientation, and temperature data analysis. The second meeting was directed toward investigation using the PhET Greenhouse

Effect simulation and group discussions. The third meeting was devoted to developing projects related to efforts to mitigate global warming, presenting the results, and conducting the evaluation (posttest). The pretest and posttest data were analyzed using the N-gain formula to assess the improvement in students' conceptual understanding. The results of the pretest and posttest score analysis are presented in Table 10.

Table 10. Descriptive Results of Pretest and Posttest

	N	Min	Max	Mean	SD
Pretest	27	10	60	31.11	11.547
Posttest	27	50	100	80.74	13.847
Valid N	27				

As shown in Table 10, the mean pretest score was 31.11, with scores ranging from 10 to 60. After the learning activities, the mean posttest score increased to 80.74, with scores ranging from 50 to 100. The difference between the pretest and posttest means indicates a substantial improvement in students' performance after participating in the learning activities.

To further determine whether the difference between the pretest and posttest scores was statistically significant, a Wilcoxon Signed-Rank Test was conducted. The results showed 27 positive ranks, 0 negative ranks, and 0 ties. This indicates that all 27 students obtained higher posttest scores than their pretest scores, with no students experiencing a decrease or maintaining the same score. The test also produced a significance value (Sig. 2-tailed) of 0.000 ($p < 0.001$), which is lower than the significance level of 0.05. Therefore, there was a statistically significant difference between students' pretest and posttest scores. This finding indicates that students' conceptual understanding significantly improved following the implementation of the developed E-LKPD integrated with the Problem-Based Learning model.

The statistically significant increase should nevertheless be interpreted within the limitations of the one-group pretest-posttest design. Because the study did not involve a control group, the improvement cannot be attributed exclusively to the E-LKPD. The findings instead indicate that students' conceptual understanding increased following the implementation of the developed E-LKPD and PBL learning activities.

Based on the results in Table 10, the average pretest score was 31.11, with a minimum score of 10 and a maximum of 60, indicating that students' initial understanding of global warming material was categorized as "Low" before using the E-LKPD in the learning process. After the learning activities using the E-LKPD and the Problem Based Learning model, the average posttest score increased to 80.74, with a minimum score of 50 and a maximum of 100. This increase demonstrates that students' understanding of global warming material improved after participating in the learning process. The improvement in individual students conceptual understanding is presented in Table 11.

Table 11. N-gain Category Distribution

Category	Number of Students	Persentage
High	18	67%
Medium	8	30%
Low	1	3%
Total	27	100%

Based on Table 11, the majority of students 18 students were in the high category, 8 students were in the medium category, and only 1 student was in the low category. This indicates that the use of the Problem Based Learning-based E-LKPD integrated with temperature pattern changes was effective in improving students' conceptual understanding of global warming material. The improvement in conceptual understanding can also be seen in more detail for each indicator of conceptual understanding, as presented in Table 12

Table 12. N-Gain Results by Conceptual Understanding Indicator

Indicator	Number of Items	*Pretest*	*Posttest*	*N-gain*	Category
Explaining	5	33	84	0,76	High
Interpreting	1	26	85	0,80	High
Exemplifying	2	31	74	0,62	High
Classifying	1	37	78	0,65	High
Concluding	1	22	70	0,62	High
Overall	10	31,11	80,74	0,71	High

Based on Table 12, the average N-gain across all conceptual understanding indicators is 0.71, which falls into the High category. This indicates that the use of the E-LKPD and the Problem Based Learning model had a significant impact on improving students' conceptual understanding of global warming material. This improvement occurred because, during the learning process, students were not only receiving material but also actively engaged in problem-solving activities, analyzing phenomena, conducting investigations, participating in discussions, and formulating solutions or prevention efforts for global warming as presented in the E-LKPD. This finding is consistent with research by Fitriyah & Ghofur (2021), which states that the use of Problem Based Learning-based E-LKPD can enhance students' thinking skills because learning is carried out through stages of problem identification, investigation, and active problem-solving.

After the limited-scale trial was completed, students were given a response questionnaire to assess their evaluation of the developed E-LKPD. The student response questionnaire covered four assessment aspects: practicality, effectiveness, language, and accessibility. The results of the analysis of the student response questionnaire are presented in Table 14.

Table 14. Students Responses to the Developed E-

LKPD

Aspek	Rata-Rata Skor	Kriteria
Kepraktisan	95%	Sangat Baik
Keefektifan	98%	Sangat Baik
Kebahasaan	100%	Sangat Baik
Akses	97%	Sangat Baik
Rata-rata	97%	Sangat Baik

The results of the student response questionnaire analysis on the four aspects showed an average score of 97%, categorized as "very good." The language aspect received the highest score of 100%, indicating that the language used in the E-LKPD is clear, communicative, and appropriate for students' proficiency levels. The effectiveness aspect scored 98%, demonstrating that the E-LKPD is effective in helping students understand global warming material and supports problem-based learning processes. The accessibility aspect received a score of 97%, indicating that the E-LKPD is easily accessible at any time, providing flexibility for students to study independently. The practicality aspect scored 95%, showing that the E-LKPD is easy to use, with clear activity steps and instructions that are easy to follow. Overall, the student responses indicate that the developed E-LKPD meets the "very good" criteria in all aspects, making it suitable for use as instructional material in science learning on the topic of global warming.

CONCLUSION

Based on the findings of this study, the PBL-based E-LKPD integrated with local temperature pattern data was developed as a feasible and contextual teaching material for global warming learning. Expert validation resulted in an overall feasibility score of 99%, indicating that the E-LKPD met the criteria for use in terms of media, content, and language. The implementation of the E-LKPD was accompanied by an improvement in students' conceptual understanding. The mean score increased from 31.11 in the pretest to 80.74 in the posttest, with an N-gain of 0.71, categorized as high. The Wilcoxon signed-rank test also showed a statistically significant difference between pretest and posttest scores ($p < .001$), with all 27 students obtaining higher posttest scores. These findings suggest that the integration of local temperature data, problem-based learning activities, group investigation, and simulation can support students in connecting global warming concepts with contextual environmental phenomena. However, because this study employed a one-group pretest–posttest design, the observed improvement cannot be attributed solely to the E-LKPD.

Students also responded positively to the E-LKPD, with an overall response percentage of 97%, categorized as very good. Practically, the developed E-LKPD provides teachers with a contextual digital learning resource that connects global warming concepts with local environmental data and encourages students to engage in problem identification, investigation, discussion, and solution development. Future research should involve larger and more diverse samples, a control or comparison group, and a longer implementation period to further examine the learning outcomes and applicability of the E-LKPD in different educational contexts.

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