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The Effectiveness of Problem-Based Learning in Enhancing Students' Explaining Competence on the Thermodynamics Topic

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Abstract: Scientific literacy, particularly the competence to explain phenomena scientifically, is an important skill for enabling students to apply scientific concepts to everyday contexts and participate in informed decision-making. This study explores the effectiveness of the Problem-Based Learning (PBL) model in enhancing students' competence to explain scientific phenomena within the topic of thermodynamics, focusing on the cases of LPG and LNG. Using a quasi-experimental design with a pretest–posttest control group, participants were drawn from several public senior high schools in Samarinda, Indonesia, through cluster random sampling. The experimental group was taught using PBL supported by context-based student worksheets, while the control group received conventional, lecture-based instruction. The assessment instrument used essay questions aligned with six PISA indicators for explaining scientific phenomena, validated by experts, and confirmed to have high reliability. The findings show that students in the PBL group achieved greater improvement across all measured indicators compared to those in the conventional group. The most significant gains were observed in constructing and evaluating models, and in explaining the societal implications of scientific knowledge. These improvements were closely related to the structured stages of PBL, including problem orientation, organization of learning activities, guided investigation, development and presentation of solutions, and analysis and evaluation of the problem-solving process. Each stage fostered active engagement, collaborative discussion, the use of multiple representations, formulation and testing of hypotheses, and reflection on both process and outcome. The results suggest that PBL is effective for enhancing students' scientific literacy, particularly in explaining competence by connecting abstract thermodynamic concepts with real-life contexts. This study supports the broader adoption of PBL as a strategy to strengthen critical thinking and scientific reasoning in line with Indonesia's long-term educational objectives under the RPJPN 2025–2045 framework.

Keywords: problem-based learning, scientific literacy, thermodynamics, competence in explaining scientific phenomena.

▪ INTRODUCTION

Scientific literacy refers to the ability of individuals or groups to engage with science-related issues and ideas, encompassing understanding, applying, and evaluating scientific information to solve everyday problems and participate in relevant discussions (OECD, 2019). According to OECD (2018), scientific literacy is not solely about understanding scientific knowledge, but also the ability to apply that knowledge in real-life contexts and to participate in discussions and decision-making related to scientific issues in society. Scientific literacy enables students to use scientific knowledge, identify questions, and draw evidence-based conclusions to understand and make decisions about the natural world and human interactions with the environment (Ardiyanti et al., 2019). Scientific literacy is a critical component of 21st-century competencies and is essential for preparing superior human resources to support national development. In alignment

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with Indonesia's long-term strategic vision as outlined in the National Long-Term Development Plan 2025–2045, the government emphasizes strengthening the quality of education through mastery of scientific literacy and critical thinking skills. This policy direction is also mandated by Law Number 20 of 2003 on the National Education System, which aims to develop learners' potential to become faithful, knowledgeable, creative, independent, and responsible individuals. Within this context, scientific literacy is no longer merely an academic objective but a national development priority. However, based on PISA 2022 results, Indonesia still ranks low in scientific literacy, indicating significant gaps in students' ability to explain phenomena using scientific reasoning. Addressing this issue requires a pedagogical shift toward student-centered, inquiry-based learning models that can bridge the gap between abstract scientific knowledge and real-world application.

According to data from the PISA assessment conducted by the OECD in 2022, Indonesia ranked 67th out of 81 participating countries in scientific literacy (OECD, 2022). Furthermore, UNESCO statistics reveal that reading interest in Indonesia is alarmingly low (0.001%). This means that out of 1,000 Indonesians, only one person regularly reads. In a study titled World's Most Literate Nations Ranked by Central Connecticut State University (2016), Indonesia ranked 60th out of 61 countries. These findings highlight the low levels of reading, mathematical, and scientific literacy among Indonesian students (Srirahayu & Arty, 2018).

Science literacy was assessed through the study conducted by OECD every three years (Mellyzar et al., 2022). This science framework describes three scientific competencies and an environmental science competency consisting of three parts. The science framework also describes three types of knowledge needed by students to master these competencies, three main contexts that students will face in scientific challenges, and aspects of science identity that are considered important (OECD, 2025). The three competencies developed in science education require three forms of knowledge, namely content knowledge, procedural knowledge, and epistemic knowledge (OECD, 2025).

Indonesian students generally possess only basic recall and recognition of scientific facts, but lack the ability to communicate, connect topics, and apply complex and abstract scientific concepts (Fathurrohman, 2020). Learning is still focused on memorizing basic concepts without relating them to everyday life (Sarminah, 2018). Science instruction often fails to connect theoretical knowledge with real-world phenomena due to a lack of experiential learning (Permanasari, 2016). Science teachers still predominantly use routine questions that do not promote higher-order thinking. However, the current demands of education require non-routine, literacy-based tasks (Mellyzar et al., 2022). Physics is often perceived as a difficult subject, leading to low motivation among students, disinterest in learning, and ultimately, poor academic performance (Agustin et al., 2017). Selecting appropriate instructional models is essential in designing effective learning activities to optimize students' scientific literacy (Hafizah & Nurhaliza, 2021). The use of well-structured learning models and media plays a crucial role in enhancing students' scientific literacy. A relevant study by Azizah et al. (2021) found an increase in students' understanding of scientific literacy through specific learning strategies, and proposed the Problem-Based Learning (PBL) model as an effective approach. Similarly, Nurtanto et al. (2019) emphasized that PBL can develop scientific literacy as a target outcome. Problem-based learning encourages active learning by solving science-related problems and promotes independence, creativity, and critical thinking.

This study presents a novel approach by specifically examining the effectiveness of the Problem-Based Learning (PBL) model in developing students' competence in explaining scientific phenomena, particularly in the topic of thermodynamics. Unlike previous studies that have generally focused on learning outcomes or critical thinking skills, this research targets scientific competencies involving explanations of abstract concepts such as the laws of thermodynamics, Gay-Lussac's law, pressure, and temperature. Moreover, this study contributes new insights by focusing on thermodynamics often regarded as a challenging subject due to its abstract nature and need for deep conceptual understanding.

The stages in the PBL model are directly related to the competency indicators for explaining phenomena scientifically developed by PISA. In the problem orientation stage, students are confronted with real phenomena that encourage them to identify and formulate scientifically relevant questions. The stage of organizing students to learn and guiding individual/group investigations in this section encourages students to gather information, remember, and apply scientific knowledge, and develop and test scientific hypotheses or models. Next, in the development and presentation stage, students are trained to construct evidence-based explanations, use scientific representations, and explain the implications of scientific concepts for society and the environment. Finally, through analyzing and evaluating the problem-solving process, students critically evaluate their thinking processes and learning outcomes, which strengthens scientific skills in constructing arguments and assessing the validity of a scientific explanation.

Student worksheets were explicitly designed to support the Problem-Based Learning (PBL) model, providing a clear structure for students in solving problems, helping them to organize information and formulate solutions, which contributes to the development of critical thinking skills. Previous research showed that students who learn using the PBL model and use student worksheets achieve better learning outcomes compared to traditional methods. PBL model not only enhances conceptual understanding but also students' ability to apply scientific knowledge in real-life situations. The findings of this study can serve as a foundation for the development of more innovative and interactive curricula, particularly in science education. It is expected that the implementation of the PBL model and student worksheets can become a more widely adopted instructional model across various science topics, not limited to thermodynamics. Therefore, the results of this study are expected to guide for implementing of PBL with a stronger focus on complex material in physics education and support competency-based education policies relevant to today's challenges.

This research also supports the direction of national development policy in order to realize "Indonesia Emas" 2045 as stated in the Law of the Republic of Indonesia Number 59 of 2024 concerning the National Long-Term Development Plan for 2025–2045. In the document, the development of superior human resources is one of the main pillars, with an emphasis on improving the quality of education and strengthening 21st-century competencies, including scientific literacy and critical thinking skills. In line with that, Law Number 20 of 2003 concerning the National Education System mandates that education must be able to develop the potential of students to become faithful, knowledgeable, creative, independent, and responsible people. Therefore, the application of learning models such as Problem-Based Learning, which has been proven effective in improving the ability to explain scientific phenomena, is a concrete step in supporting the achievement of long-term strategic national education goals.

▪ METHOD

Participants

The population in this study was all grade XI students in the three schools. The sampling technique used was cluster random sampling, taking into account the similarity of characteristics between classes. The sample consisted of the experimental group, which consisted of 99 students, and the control group, with 94 students.

Research Design and Procedures

This research is a quantitative study using a quasi-experimental method. The design used was a Pretest-Posttest Control Group Design, consisting of two groups of students: an experimental group and a control group. The experimental group received treatment with the PBL model for the topic of LNG and LPG. In contrast, the control group received the LNG and LPG topic through a lecture method. This design was chosen to test the effectiveness of the PBL model on the competence to explain phenomena scientifically. This research was conducted in the even semester of the 2024/2025 academic year at three high schools in Samarinda City: SMAN 9 Samarinda, SMAN 11 Samarinda, and SMAN 13 Samarinda. The research was conducted from April to May 2025. The implementation of PBL in the experimental class followed stages that had been adjusted to the competency indicators for explaining scientific phenomena from PISA 2025. The summary of the stages of problem-based learning in this study is present in Table 1.

Table 1. Indicators of scientific literacy competence: explaining scientific phenomena

Problem-Based Learning Syntax	Student Activities	Teacher Activities	The Relationship With Competency Indicators Explains Phenomena Scientifically
Orienting students to the problem	Observe the phenomena, identify problems, and ask scientifically relevant questions	present real-world phenomena related to LPG and LNG, supported by relevant data	Recalling and applying appropriate scientific knowledge
Organizing students for learning	Form groups, formulate hypotheses, and plan investigation steps	Explain the tasks and divide students into groups	Using various forms of representation and translating them
Guiding individual and group investigations	Collect information from various sources, create tables and graphs, and analyze data.	Facilitate data collection, analysis, and application of relevant concepts.	Making and validating accurate scientific predictions and solutions Recognizing and developing clear hypotheses about real-world phenomena

Developing and presenting solutions	Prepare evidence-based explanations, use diagrams/graphs, and present findings.	Provide opportunities for group presentations and feedback	Identifying, constructing, and evaluating models
Analyzing and evaluating the problem-solving process	Evaluate arguments, review the validity of explanations, and suggest improvements.	Lead a reflection and discussion on the strengths and weaknesses of solutions.	Explaining the potential implications of scientific knowledge for society

Instrument

The instrument used in this study was an essay test that measures the competence to explain phenomena scientifically based on six indicators from PISA 2025. The instrument consisted of 10 essay questions with an assessment using a 1-5 scale rubric. Answer score 5 = very good, answer score 4 = good, answer score 3 = sufficient, answer score 2 = less, answer score 1 = very less, answer score 0 = no answer. The test instrument first went through a content validity test validated by a physics expert lecturer. The validation process was carried out qualitatively and quantitatively using a 1-4 scale. The validation focused on the alignment between indicators and learning objectives, the clarity of the question formulation, and the suitability of the language to the level of student understanding. The reliability test was carried out using the Cronbach's Alpha formula on the results of a limited trial. Reliability is declared high if the reliability coefficient value is higher than 0.6.

The test indicators were aligned with the competency of explaining scientific phenomena, and were adapted to the real-world phenomena presented in the learning process. The indicators of scientific literacy competence are presented in Table 2.

Table 2. Indicators of scientific literacy competence: explaining scientific phenomena

No	Indicators	Description of Measured Ability	Item Number
1	Recalling and applying appropriate scientific knowledge	a. Students can remember the physical and chemical properties of LNG and LPG, such as boiling point, vapor pressure, and molecular composition. b. Students can remember scientific concepts about boiling point and changes in the state of matter.	1.2
2	Using various forms of representation and translating them	c. Students can represent tables in graphs d. Students can interpret graphs that have been created	3.4
3	Making and validating accurate scientific predictions and solutions.	e. Students can predict what will happen to LNG when the storage temperature rises.	5
4	Identifying, constructing, and evaluating models	f. Students can identify the differences between LNG and LPG g. Students can identify the driving factors for switching from LPG to natural gas networks	6.7

5	Recognizing and developing clear hypotheses about real-world phenomena	h. Students can hypothesize the relationship between storage temperature and pressure in a cryogenic tank	8
6	Explaining the potential implications of scientific knowledge for society	i. Students can calculate the reduction in CO_2 emissions if there is a switch from LPG to natural gas j. Students can explain the environmental impact of using natural gas compared to LPG (related to CO_2)	9.10

Data Analysis

The data analysis techniques used in this study consisted of several stages. Mode analysis was conducted to identify the most frequent scores in students' responses for each indicator (Untari, 2020). Scores ranged from 0 to 5, representing mastery levels from 0% (no response or irrelevant) to 100% (correct answer). Normality testing was performed using the Shapiro-Wilk method with IBM SPSS Statistics version 27. The data were considered normally distributed if the significance value was ≥ 0.05. Homogeneity testing was used to determine whether the variances between the two groups were equal; data were considered homogeneous if the significance value was ≥ 0.05.

An independent samples t-test was used to determine whether there was a significant difference between the mean scores of the experimental and control groups. A significance value > 0.05 indicated no significant difference, while a value < 0.05 indicated a significant difference. If the normality assumption was not met, the Mann-Whitney U test was used as a non-parametric alternative (Quraisy & Madya, 2021). In this test, an Asymp. Sig. value > 0.05 indicated no significant difference, while a value < 0.05 indicated a significant difference.

Lastly, the N-Gain analysis was applied to measure the improvement in students' ability to explain scientific phenomena by comparing pretest and posttest scores using the formula developed by Coletta and Steinert (2020). In this study, the N-Gain analysis was used to determine the level of improvement in students' competence to explain scientific phenomena from pretest to posttest. The results were categorized into three levels: a high category for N-Gain values equal to or greater than 0.70, a medium category for values between 0.30 and 0.69, and a low category for values equal to or less than 0.30. A high category score indicates a substantial improvement in competence, a medium category score reflects a moderate improvement, and a low category score represents only a slight improvement after the learning intervention.

▪ RESULT AND DISSCUSSION

To determine the effectiveness of the Problem-Based Learning (PBL) model on the competency of explaining phenomena scientifically, student learning outcomes were measured through pre-tests and post-tests. The control class used conventional learning, while the experimental class used a problem-based learning approach. Before learning, the average pre-test score for the control class was 43.31, while the experimental class was 38.88. This value indicates that the initial ability of both groups in explaining scientific phenomena was relatively low and not significantly different. After learning, the experimental class that received the PBL model experienced an increase in the average post-test score to 75.25, an increase of 36.37 points. Meanwhile, the control class that used the conventional method only experienced an increase in the average post-test score to 49.21, an increase of 5.90 points. This difference in increase indicates that the application of PBL is significantly more effective in improving students' ability to understand thermodynamic concepts and relate them to real phenomena, such as the differences in the characteristics of LPG and LNG, compared to conventional learning, which tends to make students passive.

The mean score aims to determine the level of mastery of each competency in explaining phenomena scientifically. Through the average score, it is possible to identify which indicators have shown significant improvement and which still require more attention. The mean score was obtained after conducting pre- and post-tests at three schools: SMAN 9 Samarinda, SMAN 11 Samarinda, and SMAN 13 Samarinda.

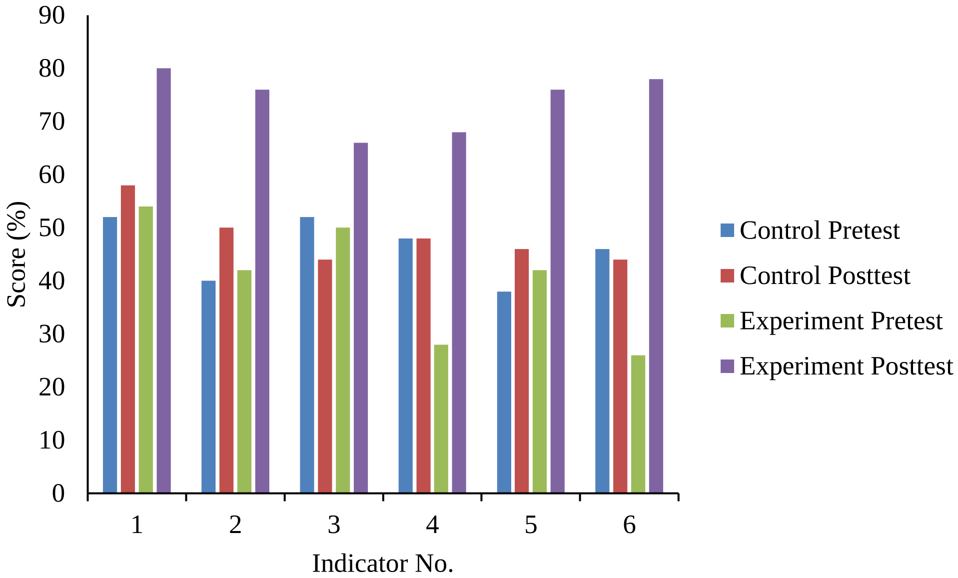

Figure 1. Pretest and posttest scores based on indicators

In the experimental class, the indicator with the highest average score after learning was related to explaining the implications of scientific knowledge for society. This indicates that students were better able to connect scientific concepts with environmental and social issues after the implementation of problem-based learning. Meanwhile, the indicator with the lowest average score before learning was identifying, constructing, and evaluating models, and explaining scientific implications for society. This indicates that students' ability to think abstractly and relate science to real-world contexts was still low before the implementation of the problem-based learning model. Conversely, in the control class, improvement across indicators was uneven. Some indicators showed only minor changes, and some even decreased after learning. This indicates that the conventional approach is less able to develop all aspects of competency optimally.

The implementation of Problem-Based Learning (PBL) in this study was designed to align with the competency indicators and test item indicators listed in Table 1. For the competency indicator recalling and applying relevant scientific knowledge with the test item indicator identifying relevant physical quantities and explaining the appropriate scientific concepts for a phenomenon, the dominant PBL syntax was the problem orientation stage, where the teacher presented the phenomenon of differences in LNG and LPG storage, prompting students to identify quantities such as pressure, temperature, and density, and connect them with the ideal gas law and phase change concepts. The competency indicator, formulating and developing clear hypotheses about real-world phenomena, with the test item indicator proposing predictions or hypotheses about observed phenomena based on scientific concepts, was facilitated in the stage of organizing students for learning, where group discussions encouraged the development of targeted hypotheses to be tested in the investigation stage. The competency indicator using and translating various forms of representation, with the test item indicator presenting data in tables, graphs, or diagrams, and interpreting their meaning, was realized in the stage of guiding individual and group investigations, as students processed data into pressure–temperature graphs and interpreted the patterns according to Gay-Lussac’s law. The competency indicator, making and validating scientific predictions and solutions, with the test item indicator, making predictions of an event’s outcome and proposing evidence-based solutions, was supported in the stage of developing and presenting products, where students designed technical solutions, such as cryogenic tank designs, based on analysis results. Furthermore, the competency indicator identifying, constructing, and evaluating models with the test item indicator constructing models or diagrams that depict relationships among variables in a phenomenon and evaluating their agreement with data was also achieved in the stage of developing and presenting products through the creation of models showing the relationship between temperature, pressure, and phase of gas storage. Lastly, the competency indicator explaining the implications of scientific knowledge for society, with the test item indicator relating learned scientific concepts to social, environmental, or public policy issues, was facilitated in the stage of analyzing and evaluating the problem-solving process, where students connected their learning outcomes to environmental impacts and national energy policy considerations.

The normality test aims to determine whether the data is normally distributed or not. The normality test was carried out using SPSS software version 27 for Windows with the Shapiro-Wilk technique. The calculation of the normality test was carried out on the results of the pre-test and post-test data, which can be seen in the appendix. The results of the normality test calculation can be seen in the following Table 3.

Table 3. Normality test

Class	**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**
Control Pretest	.967	94	.018
Experiment Pretest_	.968	99	.015
Control Posttest	.988	94	.523
Experiment Posttest_	.979	99	.110

Based on the SPSS output, the pretest results of the control class and the experimental class are not normally distributed, and the posttest results of the control and experimental classes are normally distributed. The homogeneity test aims to determine whether several variations of data from the population have the same variance or not. The homogeneity test was carried out using the help of SPSS software version 27 for

Windows. From the results of the homogeneity test, it was found that the variance of the pre-test data for students in the control class and experimental class was the same or homogeneous. The results of the homogeneity test can be seen in Table 4.

Table 4. Homogeneity test

Test of Homogeneity of Variances			
Result			
Levene Statistic	df1	df2	Sig.
.000	1	193	.293

The t-test analysis was conducted to determine significant differences in student learning outcomes in the experimental class with the Problem-Based Learning (PBL) model and the control class with conventional learning. The t-test was conducted using SPSS version 27 for Windows software. Because the control class posttest data met the assumption of normality, a parametric test (independent sample t-test) was used. The results showed a significant difference in treatment between the two classes in terms of scientific explanation ability. The results of the t-test calculation can be seen in Table 5.

Table 5. Independent samples T-Test results

Variable	**t-value**	**Sig. (2-tailed)**
Posttest (Control vs Experiment)	-25.977	0.000

The t-test using n-gain scores is a test that can provide a general overview of the increase in learning outcome scores between before and after treatment. The N-Gain score is the difference between the posttest and pretest scores. The N-Gain test was conducted with the help of the SPSS version 27 for Windows. Based on the results, it is known that the experimental class using the PBL model experienced an increase in the competence of explaining phenomena scientifically in the medium category, while the control class using conventional learning only showed an increase in the low category. The results of the N-Gain values are presented in Table 6.

Table 6. N-Gain score

Class	**Mean pretest**	**Mean posttest**	***N-Gain***	**Criteria**
Control	43.31	49.21	0.05	Low
Experiment	38.88	75.25	0.58	Medium

The results of the study show that conventional learning leads to a lower improvement in students' competence to explain scientific phenomena compared to the PBL model. One of the main reasons for this difference lies in the teaching approach used in conventional learning. Conventional instruction is considered less effective, particularly when integrated with student worksheets, especially those based on scientific phenomena, due to its teacher-centered nature and limited student interaction and exploration. In this model, teachers mainly deliver content through lectures, while students passively listen and take notes. This approach does not provide sufficient opportunities for investigation, group discussion, or active problem-solving elements that are central to the use of phenomenon-based student worksheets. This limitation is supported by Sugiyanto (2009), who argues that conventional models mostly activate low-level cognitive skills such as remembering and understanding but lack the capacity to stimulate analytical and synthetic thinking skills needed in science learning. As a result, conventional learning does not align with the goals and structure of phenomenon-based student worksheets, as it does not allow students to construct knowledge through scientific processes.

In contrast, the PBL model implemented in the experimental class positions the teacher not just as a source of knowledge, but as a facilitator who designs problem-solving situations and guides students through investigative processes. Students are encouraged to identify problems, gather information, engage in group discussions, and formulate solutions based on logical arguments. In other words, the learning process becomes student-centered, allowing learners to be actively involved in building their knowledge. PBL has proven effective in enhancing students' competence in explaining scientific phenomena because it promotes active engagement in solving real-world problems through inquiry. (Arends, 2012) stated that PBL fosters a learning environment that encourages students to become active participants in constructing their understanding through investigation, discussion, and reflection. The focus shifts from teacher-led instruction to students' cognitive processes in understanding and relating concepts to real-life contexts. In PBL, students are presented with contextual problems or phenomena and are guided to formulate questions, analyze information, develop hypotheses, and provide explanations grounded in scientific reasoning.

Although the implementation of the PBL model has shown an increase in students' competence in explaining scientific phenomena, this improvement is still in the moderate category and has not yet reached the high category. One possible cause is the relatively short duration of the intervention, which only lasted a few meetings during one semester, so there was not enough time to explore thermodynamic concepts in depth. Furthermore, the abstract and contextual nature of thermodynamics material, such as the laws of thermodynamics, the relationship between pressure and temperature, and the characteristics of LNG and LPG gases, requires higher-order thinking skills and a strong mathematical understanding. While PBL can help bridge understanding through real-world contexts, some students may still experience difficulties in teaching theory with real-world applications. Limitations in prior experience, diverse student base abilities, and adaptation to a learning model that demands independence and active participation can also be factors that hinder the achievement of high-level improvements. Therefore, more intensive and sustainable intervention is needed to maximize the impact of PBL.

Therefore, it can be concluded that the Problem-Based Learning model is more effective in improving students' competence in explaining scientific phenomena compared to conventional learning, as evidenced in the three participating high schools. The medium-category N-Gain scores in the experimental classes indicate a significant positive impact of PBL on students' scientific explanation skills. Although the average pretest scores in the experimental class were initially low, the implementation of PBL successfully fostered active student engagement in the learning process, which was reflected in the consistent increase in posttest scores. While the improvement did not reach the high category overall, it demonstrates that PBL is capable of addressing the limitations of the more passive conventional approach.

These findings are consistent with those of (Riyanto et al., 2024), who found that PBL significantly enhances students' critical thinking skills compared to traditional approaches. PBL promotes active student involvement in contextual problem-solving, enabling a deeper and more logical understanding of scientific concepts. Problem-based problem-solving around the transition from LPG (Liquefied Petroleum Gas) to LNG (Liquefied Natural Gas) in a Problem-Based Learning (PBL) model provides a powerful, concrete context for students to understand abstract concepts in thermodynamics, such as Gay-Lussac's law, the relationship between pressure and temperature, and the characteristics of gases in closed systems. When students are asked to analyze why the government is pushing for a transition from LPG to LNG, they not only review policy or environmental aspects but also explore the physical and chemical differences between the two types of gas. For example, students will discover that LNG is stored at much lower temperatures and pressures to remain liquid, and that small temperature changes can cause significant changes in pressure, in accordance with Gay-Lussac's law. In solving problems, such as how to ensure the safety of LNG distribution to households or how to design efficient storage tanks, students are required to understand the complex relationships between temperature, pressure, and gas volume. By linking a concrete context, the energy transition, with scientific principles, students build conceptual understanding not simply through memorization, but through investigation and data-driven reasoning. This is the main strength of PBL: helping students connect actual phenomena in life and national policies with scientific principles that initially seemed abstract, so that the understanding gained becomes deeper, relevant, & more meaningful.

Similarly, a study by Hidayati & Sunardin (2023) supports this result by showing that PBL significantly improves students' ability to understand and explain science concepts both in written and oral form. Furthermore, Sugiyanto (2009) emphasized that PBL is effective in fostering higher-order thinking skills by encouraging students to analyze, evaluate, and create solutions based on evidence and data. Research by Marhaeni (2021) also confirmed that PBL, when combined with phenomenon-based student worksheets, significantly enhances students' scientific literacy, especially in explaining phenomena and developing critical thinking. For physics teachers who wish to implement the PBL model, the first step is to select contextual problems that are relevant to everyday life and directly related to the physics concepts being studied. In implementing this model, teachers need to act as facilitators who encourage discussion, provide stimulating questions, and guide the scientific inquiry process, rather than as one-way information providers, in addition to thermodynamics, various other physics topics are also very suitable for the PBL approach, such as the greenhouse effect (for radiation and heat energy), motor vehicle collisions (for the concepts of momentum and Newton's laws), electrical blackouts (for understanding the concepts of electricity and energy), and flooding due to forest destruction (for applying the concepts of fluid pressure and buoyancy). By raising contextual issues close to students' realities, teachers not only build a stronger understanding of concepts but also foster critical thinking skills, problem-solving, and scientific awareness of social and environmental issues.

▪ CONCLUSION

This study concludes that the Problem-Based Learning model is effective in enhancing students' competence in explaining scientific phenomena, particularly on the topic of thermodynamics involving LPG and LNG. The implementation of problem-based learning encourages active student engagement in contextual problem-based learning, thereby fostering the development of scientific thinking skills. Compared to conventional instruction, problem-based learning has a more significant impact on students' ability to understand and relate physics concepts to real-life situations. These findings support the application of problem-based learning as a relevant alternative approach to strengthen science literacy at the secondary school level. Although the research results demonstrate the effectiveness of the PBL model in improving the ability to explain scientific phenomena, several limitations warrant consideration. Different teacher involvement in the learning process could potentially introduce bias, particularly if teachers in the experimental class are more enthusiastic or have a better understanding of PBL than teachers in the control class. These differences could indirectly impact the quality of implementation and learning outcomes. Third, in data analysis, the use of mode as a measure of central tendency for each indicator may limit the depth of interpretation, as it does not account for the entire distribution of student scores.

▪ REFERENCES

Agustin, N. P., Lesmono, A. D., & Wahyu, R. B. (2017). *Pembelajaran fisika di sma dengan menggunakan model kooperatif tipe STAD (Kajian: Di SMAN 1 Tapen Bondowoso)* [physics learning in high school using the STAD type cooperative model (study at SMAN 1 Tapen Bondowoso)]. *Jurnal Pembelajaran Fisika*, *6*(2), 196–202.

Ardiyanti, Y., Suyanto, S., & Suryadarma, I. G. P. (2019). The role of students' science literacy in Indonesia. *Journal of Physics: Conference Series, 1321*(3). https://doi.org/10.1088/1742-6596/1321/3/032085

Arends, R. I. (2012). *Learning to Teach*. In Central Connecticut State University (Switzerland) (Vol. 11, Issue 1).

Azizah, D. N., Irwandi, D., & Saridewi, N. (2021). *Pengaruh model pembelajaran problem based learning berkonteks socio scientific issues terhadap kemampuan literasi sains siswa pada materi asam basa* [the influence of problem based learning model with socio-scientific issues context on students' scientific literacy skills in acid-base material]. *Jurnal Riset Pendidikan Kimia, 11*(1), 12–18.

Fathurrohman. (2020). Pengembangan modul fisika dasar I berbasis literasi sains. *Pancasakti Science Education Journal*, 5(9), 4–11.

Hafizah, E., & Nurhaliza, S. (2021). *Implementasi problem based learning (pbl) terhadap kemampuan literasi sains siswa. Quantum: Jurnal Inovasi Pendidikan Sains*, 12(1), 1. https://doi.org/10.20527/quantum.v12i1.9497

Hidayati, N. D., Sunardin, I. M. (2023). *Pengaruh model pembelajaran problem-based learning terhadap pemahaman konsep ipa siswa kelas 4 sd negeri doyong 4 kota tangerang* [the influence of the problem-based learning model on the understanding of science concepts of grade 4 students of doyong 4 elementary school, tangerang city]. *Jurnal Ilmiah Wahana Pendidikan*, 9(November), 507–517.

Marhaeni, H. N. (2021). *Efektivitas lkpd berbasis problem based learning untuk meningkatkan kemampuan pemecahan masalah matematis siswa sma negeri 1 imogiri. Jurnal Pendidikan Surya Edukasi (JPSE),* 7(2), 85–96. https://doi.org/10.37729/jpse.v7i2.7607JPSE

Mellyzar, M., Zahara, S. R., & Alvina, S. (2022). *Literasi sains dalam pembelajaran sains siswa SMP* [scientific literacy in science learning for middle school students]. *Pendekar: Jurnal Pendidikan Berkarakter, 5*(2), 119. https://doi.org/10.31764/pendekar.v5i2.10097

Nurtanto, M., Sofyan, H., Fawaid, M., & Rabiman, R. (2019). Problem-based learning (PBL) in Industry 4.0: Improving learning quality through character-based literacy learning and life career skill (LL-LCS). *Universal Journal of Educational Research*, *7*(11), 2487–2494. https://doi.org/10.13189/ujer.2019.071128

OECD. (2018). *PISA 2015*. PISA Result In Focus. OECD.

OECD. (2019). *PISA 2018 assessment and analytical framework: reading, mathematics, and science*. OECD Publishing. OECD. https://doi.org/10.1787/b25efab8-en

OECD. (2022). *PISA 2022 Assessment and analytical framework: mathematics, reading, and science.* OECD. https://www.oecd.org

Permanasari, A. (2016). STEM Education: *inovasi dalam pembelajaran sains* [innovation in science learning]. Prosiding Seminar Nasional Pendidikan Sains VI, 23–34.

Quraisy, A., & Madya, S. (2021). *Analisis nonparametrik mann whitney terhadap perbedaan kemampuan pemecahan masalah menggunakan model pembelajaran problem-based learning* [mann whitney non-parametric analysis of differences in problem-solving ability using the problem-based learning model]. *VARIANSI: Journal of Statistics and Its Application on Teaching and Research, 3*(1), 51–57. https://doi.org/10.35580/variansiunm23810

Riyanto, M., Asbari, M., & Latif, D. (2024). *Keefektifan problem based learning terhadap kemampuan berpikir kritis. Journal of Information Systems and Management*, 03(01), 20–25. https://doi.org/10.52005/belaindika.v1i2.14

Sarminah. (2018). *Penerapan pendekatan kontekstual untuk meningkatkan hasil belajar IPA Kelas VI SD Negeri 004 tembilahan kota kecatamatan tembilahan* [implementation of a contextual approach to improve science learning outcomes for grade vi of sd negeri 004 tembilahan city, tembilahan district]. *Jurnal PAJAR (Pendidikan dan Pengajaran) 2*(2), 1–23.

Srirahayu, R. R. Y., & Arty, I. S. (2018). *Pengembangan instrumen experiment performance assessment untuk menilai keterampilan proses sains dan kerja sama* [Development of an experimental performance assessment instrument to assess science process skills and collaboration]. *Jurnal Penelitian Dan Evaluasi Pendidikan, 22*(2), 168–181. https://doi.org/10.21831/pep.v22i2.20270

Sugiyanto. (2009). *Model-model pembelajaran inovatif*. In Surakarta: UNS.

Untari, D. T. (2020). *Buku ajar statistik 1*. CV. Pena Persada.

▪ APPENDIX

SOAL PRE-TEST DAN POST-TEST FISIKA KOMPETENSI MENJELASKAN FENOMENA SECARA ILMIAH MATERI TERMODINAMIKA

a. Bacalah teks bacaan terlebih dahulu sebelum menjawab soal!
b. Pengerjaan soal tidak boleh menggunakan handphone/sejenisnya serta bekerja sama/berdiskusi dengan teman!
c. Apabila terdapat kekeliruan pada soal, siswa diperbolehkan bertanya kepada pengawas!

d. *Jangan lupa berdoa dan good luck!*

Nama :
Kelas :

1. *Seorang insinyur bernama Rizky sedang mempelajari perbedaan antara LNG (Liquefied Natural Gas) dan LPG (Liquefied Petroleum Gas). Ia menemukan bahwa LNG memerlukan suhu sangat rendah, yaitu -162°C, untuk mencairkan gas alam, sementara LPG dapat dicairkan pada tekanan relatif rendah dan suhu yang lebih tinggi. Dari bacaan tersebut, mengapa LNG memerlukan suhu -162°C untuk mencair, sementara LPG dapat dicairkan pada suhu yang lebih tinggi?*
2. *LPG (Liquefied Petroleum Gas) mempunyai titik didih pada suhu -42°C. Jelaskan perubahan wujud yang terjadi pada titik didih tersebut!*
3. *LPG (Liquefied Petroleum Gas) adalah campuran gas hidrokarbon, terutama propana dan butana, yang digunakan sebagai bahan bakar. n-Butana, salah satu komponen LPG, memiliki sifat yang sangat bergantung pada suhu dan tekanan. Seorang teknisi bernama Rudi sedang mempelajari sifat-sifat n-butana dengan mengumpulkan data suhu dan tekanan untuk mencairkan n-butana seperti pada tabel berikut:*

Suhu ℃	Tekanan (kPa)
20	115
30	200
40	350
50	510

Dari data diatas buatlah grafik yang menunjukkan hubungan antara suhu dan tekanan n-butana berdasarkan data di atas!

4. *Dari grafik jawaban nomor 3 bagaimana hubungan tekanan dan suhu untuk mencairkan n-butana?*
5. *Seorang insinyur bernama Rina bekerja di sebuah terminal penyimpanan LNG (Liquefied Natural Gas). Suatu hari, sistem pendingin di terminal tersebut mengalami gangguan, menyebabkan suhu LNG dalam tangki penyimpanan naik dari -162°C*

(suhu normal penyimpanan LNG) menjadi -150°C. Apa yang terjadi pada LNG ketika suhunya naik menjadi -150°C?

6. *Gas LNG (Liquefied Natural Gas) dan gas LPG (Liquefied Petroleum Gas) adalah dua jenis bahan bakar gas yang sering digunakan dalam kehidupan sehari-hari maupun industri. Walaupun keduaya berbentuk cair saat disimpan, ada beberapa perbedaan yang mendasar dari kedua gas tersebut. Identifikasilah perbedaan LNG (Liquefied Natural Gas) dan LPG (Liquefied Petroleum Gas) dibawah ini!*

Aspek	***LNG (Liquefied Natural Gas)***	***LPG (Liquefied Petroleum Gas)***
Komposisi Utama		
Titik didih		
Bentuk penyimpanan		
Tekanan penyimpanan		
Transportasi pengiriman		

7. *Kota Bontang dan Penajam sedang merencanakan transisi dari penggunaan LPG (Liquefied Petroleum Gas) ke jaringan gas alam (pipa gas) untuk memasok kebutuhan energi rumah tangga dan industri. Proyek ini bertujuan untuk mengurangi biaya energi dan emisi karbon. Jelaskan faktor apa saja yang mendorong pergantian gas LPG ke jaringan gas alam!*
8. *Liquefied Natural Gas (LNG) adalah gas alam yang didinginkan hingga -162°C agar tetap dalam bentuk cair. Penyimpanan LNG dilakukan dalam tangki kriogenik yang menjaga suhu rendah dan tekanan stabil.*

Berdasarkan karakteristik LNG yang harus disimpan dalam suhu sangat rendah, bagaimana hubungan antara suhu penyimpanan dan tekanan dalam tangki kriogenik?

9. *Pemeritah Samarinda sedang mempertimbangkan pergantian penggunaan gas LPG dengan Gas alam dengan skala besar, jika diketahui :*

a. *Pembakaran Pembakaran 1 kg gas LPG menghasilkan 3 kg CO_2.*
b. *Pembakaran 1 kg gas alam menghasilkan 2,75 kg CO_2.*
c. *Kota Samarinda dengan 100.000 rumah tangga menggunakan rata-rata 12 kg gas LPG per bulan.*

Berdasarkan data tersebut, mengapa gas alam dianggap lebih ramah lingkungan dibandingkan gas LPG?

10. Pemeritah Samarinda sedang mempertimbangkan pergantian penggunaan gas LPG dengan Gas alam dengan skala besar, jika diketahui :

a. Pembakaran Pembakaran 1 kg gas LPG menghasilkan 3 kg CO^2 *.*

b. Pembakaran 1 kg gas alam menghasilkan 2,75 kg CO^2 *.*

c. Kota Samarinda dengan 100.000 rumah tangga menggunakan rata-rata 12 kg gas LPG per bulan.

Hitunglah pengurangan emisi CO^2 *per bulan jika semua rumah tangga beralih ke gas alam?*