JSER

Journal of Science Education Research
Journal homepage: https://journal.uny.ac.id/index.php/jser/index

ISSN: 2597-9701

Development of Temperature and Heat Teaching Modules Based on Problem Based Learning to Improve Students' Critical Thinking

M. Putri[1], H. Akhsan[2*], Kistiono[3]
[1,2,3]*Physics Education, Faculty of Teacher Training and Education, Sriwijaya University, Indonesia*
[*]*Corresponding Author. Email: hamdiakhsan@fkip.unsri.ac.id Phone*: +6285216363154*

Abstract
This study developed a physics teaching module on temperature and heat for Grade XI students based on Problem-Based Learning (PBL), integrated with deep learning principles and PhET virtual simulations. The study was restricted to the first three stages of the 4-D model (Define, Design, Develop) due to time and resource limitations. Three experts (content, media/design, and curriculum) used Aiken's V coefficient to validate the module, and ten students from SMA PGRI Gelumbang, South Sumatra, participated in a small group trial to evaluate its usefulness using a Likert scale questionnaire that was analysed using the HEOS percentage formula. The module was classified as Very Valid based on the validation results, which showed Aiken's V coefficients ranging from 0.83 to 1.00 across all 22 indicators. For all six-usability metrics, the curriculum fell into the Practical to Very Practical category, with practicality scores ranging from 83% to 90%. Students developed preliminary theories on specific heat capacity and successfully ran PhET simulations on their own. These results, however, only represent theoretical viability (validity) and usability (practicality); the study only included ten students from a single school and lacked control groups and pretest-posttest instruments; thus, it was unable to gauge real progress in critical thinking abilities. To experimentally evaluate the module's effect on cognitive results, future studies should employ quasi-experimental designs for the Disseminate phase.

History
Received: November 19, 2025

Revised: January 28, 2026

Accepted: February 3, 2026

Keywords:
Problem based learning, deep learning, temperature and heat, PhET virtual labs, 4-D model, critical thinking.

How to cite:
Putri, M., Akhsan, H., & Kistiono. (2026). Development of Temperature and Heat Teaching Modules Based on Problem Based Learning to Improve Students' Critical Thinking. *Journal of Science Education Research*, 10(1), 15-25. doi: https://doi.org/10.21831/jser.v10i1.260265.

1. INTRODUCTION

In science education, particularly in physics, critical thinking abilities are one of the 21st-century skills that need to be strengthened since they help students analyze, assess, and solve problems in a rational and thoughtful way. With a starting score of just 47.82 and a learning completeness percentage of 29.4% (Astra et al., 2019) several studies demonstrate that 11th grade students' critical thinking abilities on the issue of temperature and heat are still low (Sujanem & Putu Suwindra, 2023). The abstract nature of the subject matter and the prevalence of traditional teacher centered learning, which tends to render students passive and dependent on memorization, are the primary causes of these findings. The difficulty of differentiating between temperature, heat, and internal energy, as well as the difficulty of comprehending the microscopic mechanics of heat transport, are two widespread misconceptions (Agus Kurniawan et al., 2020). The prevalence of traditional teacher centered learning, which tends to keep students passive and reliant on rote memorization rather than fostering conceptual understanding, exacerbates this predicament.

Temperature and heat are considered difficult topics by students (Mahmud et al., 2024), yet they are highly relevant to everyday life such as in understanding thermal insulation, cooking processes, or climate regulation. Indeed, research findings indicate that students experience serious difficulties in grasping the concepts of heat and heat transfer precisely because instruction remains dominated by lecture methods and the rote memorization of formulas, rather than promoting understanding through the analysis of real-world phenomena (Putri & Prahani, 2024). In actuality, even some Problem-Based Learning (PBL) modules developed for this topic still prioritize procedural steps over deep conceptual engagement, failing to fully integrate principles of deep learning.

It has been demonstrated that PBL is effective in improving students' critical thinking skills. Students are encouraged to actively participate in group discussions when the Problem-Based Learning (PBL) approach is implemented, share their prior knowledge, and collaborate in solving contextual problems related to temperature and heat, significantly increasing their learning activities into the active category (Safitri et al., 2023; Yovianda et al., 2019). Problem-Based Learning (PBL) encourages students to construct their own knowledge through scientific activities, group discussions, and contextual problem-solving, thereby enhancing conceptual comprehension and developing higher order thinking abilities (Serevina & Sari, 2018a). In PBL, students do not merely receive information, but actively engage in group discussions, simulation data analysis, and the construction of scientific arguments processes that directly train critical thinking skills (Adhelacahya et al., 2023). According to studies, PBL significantly improves students' learning activities and problem-solving skills, two essential pillars in the development of critical thinking (Pratiwi et al., 2020; Yovianda et al., 2019).

Additionally, PBL stimulates higher order thinking processes by encouraging students to interact with real world problems (Otoluwa et al., 2024). A meta-analysis (Liu & Pásztor, 2022) of 58 effect sizes from 50 trials provides more empirical support, demonstrating that PBL significantly improves critical thinking abilities. Research (Abdullah et al., 2024) demonstrates an increase in students' conceptual mastery and cognitive engagement even in a digital setting, with an N-gain value of 0.73. However, through interactive experiments, PhET virtual labs have been shown to be successful in assisting students in comprehending abstract physics ideas (Rahmadita et al., 2021). Lack of learning materials that promote deep information processing frequently hinders PBL implementation. Deep learning principles have not been included in many earlier works. Deep comprehension, conceptual linkages, critical analysis, and the application of knowledge in novel circumstances are all stressed in this method. According to a meta-analysis of 17 research by (Taufik et al., 2025), studying using a deep learning strategy significantly improves students' critical and scientific thinking abilities (d=0.88, high category). These results demonstrate the superiority of deep learning over rote learning. Despite being utilized as an additional tool, PhET's integration with deep learning concepts is still subpar. This potential can be maximized when combined with a structured pedagogical approach like PBL and deep learning principles. A learning strategy that promotes both active student participation and deep comprehension through contextual idea exploration is required to get over this restriction.

Learning about temperature and heat, which is often considered abstract and prone to misconceptions, can be enriched through PBL, interactive virtual experiments (PhET), and a focus on deep learning, which has the potential to create a more effective learning environment for improving critical thinking abilities. Therefore, the goal of this research is to create a PBL based learning module on temperature and heat. This module comprehensively combines the principles of deep learning and PhET virtual practicums. With this design, it is hoped that the module can function not only as a quality and practical learning resource, but also to encourage students to think critically in compliance with the requirements of the Merdeka Curriculum and 21st-century competencies.

2. LITERATURE REVIEW

2.1. Problem Based Learning

A learning approach called problem-based learning (PBL) uses actual issues as the backdrop for teaching scientific ideas to students. Instead, then just having students memorise formulas, PBL pushes them to explore phenomena like heat transfer or changes in the state of matter when it comes to temperature and heat. With this method, the emphasis is shifted from passive learning to active problem-solving. In this case, the problem that is being presented serves as a catalyst that compels students to exercise critical thinking, evaluate circumstances, and look for pertinent material in order to develop their own knowledge either alone or in groups. According to (Serevina & Sari, 2018b), PBL included into instructional materials can greatly boost student engagement since it challenges them to solve problems that are applicable to everyday life. Students must be required to work in groups and undertake scientific research in order to solve the challenges that are presented in relation to temperature and heat. Students get the ability to respect others' viewpoints, share assignments, and combine different ideas to create the best answers through the process of group cooperation, which eventually improves both their academic and social skills at the same time.

According to (Veronika Tiara et al., 2024) the PBL syntax which includes problem orientation, student organisation, enquiry, result presentation, and evaluation offers a solid foundation for developing a profound comprehension of ideas. These procedures help students comprehend the scientific method underlying each phase of problem-solving in addition to concentrating on the end product. In order for students to actually experience the process of "discovering" the concepts of temperature and heat, this model works best when accompanied by a teaching module created especially to lead students' investigative steps methodically. The module should provide clear guidance without delivering direct answers. These methodical procedures along with the module's relevant instructions will guarantee that the knowledge gained is not only theoretical but also useful and applicable.

2.2. Critical Thinking Skills

Analysing, synthesising, and assessing data obtained through reasoning or observation is a disciplined intellectual process that is known as critical thinking. Critical thinking is crucial in physics classes, especially when discussing temperature and heat, because it helps students separate scientific truths from conjecture and use ideas to address real world situations. Being able to ask why certain heat transfer processes occur and how these ideas apply in intricate new scenarios is a key component of critical thinking, which goes beyond simply learning the definitions of conduction and radiation. As a result, this capacity is the main basis for children to function as young researchers who can relate abstract ideas to tangible facts in their environment.

According to (Permatasari & Satianingsih, 2025) students who possess strong critical thinking abilities are able to construct problems in an understandable manner, offer arguments that are backed up by evidence, and arrive at logical conclusions after analysing experimental data. This ability must be taught via teaching strategies that require in-depth examination, like PBL, as it does not develop naturally. Students learn to check and assess the data they get when doing experiments on thermal expansion or heat capacity, rather of taking information at face value, through consistent practice within the PBL framework. This develops a student's capacity for focused thought, scientific scepticism, and the ability to consider a subject from multiple angles before coming to a decision.

Rizki et al. (2019) adds that the capacity to infer, organise strategies and tactics in problem-solving, and offer straightforward explanations are all signs of critical thinking. Investigative tasks included in the module's student worksheet must therefore be incorporated into the design of PBL-based teaching modules in order to encourage these indications. Additionally, in order to acquire this skill, students must engage in metacognition, which involves reflecting on their own thought processes and identifying the arguments' advantages and disadvantages. Students will learn to organise problem-solving processes methodically, assess the findings of their own investigations, and present scientific findings with compelling and logical arguments by incorporating activities that refine these markers into the lesson plan.

2.3. Module Development and the 4D Model

The methodical process of developing modules is intended to produce organised instructional resources that support students' self-directed learning. The 4D model created by Thiagarajan, which has four primary stages, Define, Design, Develop, and Disseminate is the development model used in this study. This model was chosen because it uses methodical and structured processes to create educational materials that are both reliable and successful. This method guarantees that the final module is a guided learning experience catered to particular educational goals rather than just a compilation of facts. In order to make sure that the module created is pertinent and focused, (Anggreani et al., 2025) assert that the Define stage of the 4D model is essential for examining student demands as well as the properties of the temperature and heat material. Before conducting restricted student trials, expert validation is carried out throughout the Design and Develop stages to guarantee that the module's content and design are adequate. The module's standard technical and instructional quality is ensured by this development procedure, which qualifies it for use in the classroom.

According to (Suryadi et al., 2019) the 4D model's Disseminate stage is frequently the last step in getting the verified product in front of more people, such other educational institutions or through a scientific publication. In order to accomplish the objective of improving critical thinking abilities, the temperature and heat module was developed using a 4D model, which guarantees that the finished result is both theoretically and practically feasible in authentic learning situations. This methodical approach turns the module into a powerful instrument that teachers can use to raise the standard of physics instruction.

3. RESEARCH METHOD

This study uses the 4-D development model (Define, Design, Develop, Disseminate) as proposed by (Zamsiswaya et al., 2024). However, in this study, the Disseminate stage was not implemented due to time and resource constraints.

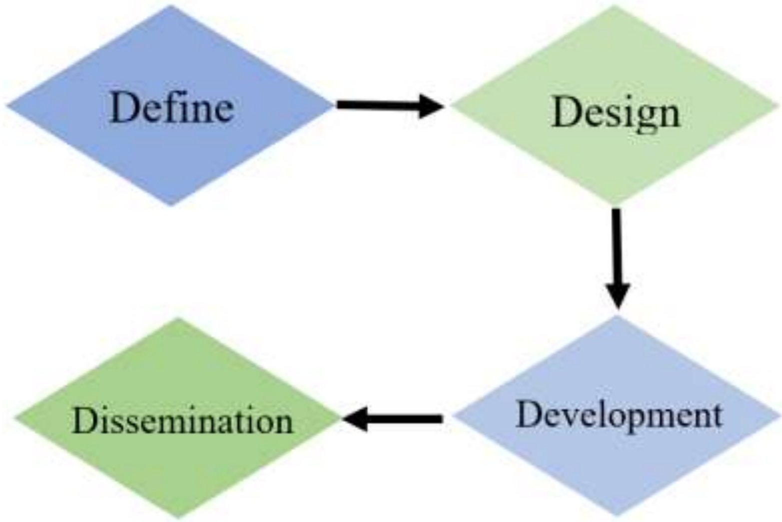

Figure 1. 4-D model flowchart

Research Type

The study is categorized as a qualitative and quantitative developmental research, aiming to produce a valid and practical physics teaching module based on Problem-Based Learning (PBL) integrated with PhET virtual labs. The research followed a formative evaluation approach, involving expert validation and small group trials to assess product quality.

Time and Place

This research was conducted from August to November 2025 in various locations in South Sumatra Province, Indonesia. The literature review and initial design were carried out at Sriwijaya University, while expert validation involved subject matter experts, media experts, and design experts, including physics teachers from SMA PLUS Negeri 2 Banyuasin III and SMKN 1 Martapura high schools. A small group trial was conducted at SMA PGRI Gelumbang South Sumatra, which was selected due to its suitability for the target student profile. There were 10 students in the trial.

Procedures

These phases, which are restricted to the development stage until the product revision can be shown below, can be summed up into three stages.

1. Define stage, in order to identify learning issues in the grade XI Heat and temperature, as well as pupils' inadequate critical thinking skills and misconceptions about temperature and heat, a requirements analysis was carried out by studying the literature. The development method for a Problem-Based Learning (PBL) module linked with PhET virtual experiments is determined by examining student characteristics and curriculum analysis (Merdeka Curriculum Phase F).
2. Design Stage, this is the first phase of creating the final product. The developed product is adapted to the subject matter and learning objectives. This stage begins with establishing the main concepts found in the temperature and heat material.
3. Development stage, is where the development product is made. After going through a revision process based on feedback from validators, the goal of this stage is to create the final version of the model and tools. Small group trials are also carried out at this point to gauge the product's usefulness.
4. Disseminate Stage, this phase involves sharing the findings of the study. Nevertheless, the Disseminate stage was not used in this investigation. The primary focus of this research is the development and validation of a PBL (Problem-Based Learning) physics module. The research procedure emphasized an iterative process of designing, validating through expert assessment, and refining the product based on feedback to ensure its quality and scientific accuracy. Therefore, this study did not extend to the dissemination phase, as its scope was determined by the goal of creating a validated prototype, not widespread implementation or commercialization. The product's practicality was assessed to confirm its usability in a controlled environment, completing the learning materials development phase.

Data Collection Technique

Non test instruments, such as survey sheets and questionnaires, were used in data gathering procedures (Hudaya Salsabila et al., 2023). The study employed purposive sampling to select participants who could provide specific information regarding the feasibility and usability of the developed module (Supriyadi et al., 2021). Three expert validators were selected based on specific criteria to ensure scientific and pedagogical soundness: a content expert, who is a senior physics teacher with a Master's degree in Physics Education and at least 5 years of experience; a media expert, who is a physics teacher specializing in instructional media and the integration of PhET simulations; and an instructional design expert, who is a certified physics teacher with over 5 years of experience in the Merdeka Curriculum. For the small group trial, ten Grade XI MIPA students were purposively selected based on two main criteria: they had already completed introductory physics courses to ensure they possessed the prerequisite knowledge, and they represented a heterogeneous mix of academic abilities (high, medium, and low). This purposive selection ensures the module's usability, clarity, and interactivity are effectively assessed across all levels within the target user profile.

Data Analysis Technique

The data collected from the validation sheets and practicality questionnaires were analyzed using quantitative descriptive techniques. Validity Analysis (Expert Assessment): To measure the validity of the module from the expert validators, this study utilized Aiken's V formula. This technique is used to quantify the agreement among raters regarding the relevance and quality of the module components, which is more robust than simple averages (Nurjanah et al., 2023). The formula used is:

$$V = \frac{\sum S}{[n(c-1)]} \times 100\%$$

Where: $S = r - l_o$

Explanation:

n: number of assessors

lo: lowest assessment score

c: highest assessment score

r: score given by assessor

The content validity criteria for module components are based on the Aiken's V coefficient value. Based on the analysis of three validators with a five-point Likert scale, the component is declared valid.

Table 1. Interpretation of Validity Index

Aiken index scale range	Description
V>0.84	Very Valid
0.68<V<0.84	Valid
0.52<V<0.68	Moderatly Valid
0.36<V<0.52	Less Valid
V≤0.36	Not Valid

(Hafild et al., 2025)

For small group trials, the percentage of one-to one evaluation and small group (HEOS) results is calculated using the following formula:

$$HEOS = \frac{questionnaire\ score}{maximum\ score} \times 100\%$$

Table 2. Results Categories

Percentage %	Classification
86 ≤ HEOS ≤ 100	Very Practical
70 ≤ HEOS < 86	Practical
56 ≤ HEOS < 70	Less Practical
HEOS < 56	No Practical

(Wiyono, 2015)

4. RESULT AND DISCUSSION

4.1 Development of PBL-Based Teaching Modules with Integration of Deep Learning and PhET Virtual Lab

Critical thinking skills were operationalized based on Ennis's framework, which includes five core aspects: basic explanation, the foundation for judgment, deduction, sophisticated explanation, conjecture, and integration (Darmawati & Mustadi, 2023). These dimensions guided the design of assessment instruments and problem scenarios in the module. Using a 4-D development approach with four stages Define, Design, Develop, and Disseminate this study created a physics teaching module for Grade XI students' high school will engage in problem-based learning (PBL) on the subject of temperature and heat. However, due to time and resource limitations, the Disseminate stage was not carried out in this study. As a result, the study's scope was restricted to the Define, Design, and Develop phases. The outcomes depending on the use of these three steps are discussed in the following.

Research items are designed based on the identification of learning challenges during the Define stage (Sajiwo et al., 2019). A review of the literature, a study of curriculum documents, and the identification of student characteristics are all used in needs analysis. As evidenced by their inability to differentiate between the concepts of heat and temperature and evaluate heat flow (Astari et al., 2022; Kapul et al., 2023; Reyza Arief Taqwa & Suyudi, 2020; Yuliana et al., 2023), as well as their poor critical thinking abilities when examining common thermal phenomena (Lubis & Sabani, 2023; Sundari & Sarkity, 2021). According to an analysis of the learning objectives for Phase F of the Merdeka Curriculum, students must be able to evaluate physical concepts and apply them in practical situations in order to understand the material on temperature and heat. A problem-based approach combined with PhET virtual experiments was selected as the primary method since it is expected that grade XI students have a basic understanding of hot and cold phenomena and experience with changes in the form of substances. The ability of the PhET Energy Forms and Changes simulation to illustrate abstract ideas like thermal energy transfer and heat capacity led to its selection. This aligns with the results (Abadi et al., 2025) that numerous empirical studies demonstrate that using PhET simulations enhances students' conceptual understanding of temperature and heat, particularly in differentiating between temperature and heat, comprehending heat transfer, and analyzing the relationship between variables because its interactive visualization enables virtual exploration of thermal phenomena that cannot be accomplished through traditional learning.

A five-step PBL structure problem orientation, organizing learning, group inquiry, development and presentation of outcomes, and process analysis and evaluation was used to design the module during the Design stage. Based on a meta-analysis showing that PBL significantly improves high school pupils' capacity for critical thought when studying physics (Arifah et al., 2021) it was chosen to address the issues found during the Define stage. Every step is connected to contextual occurrences, such as how thermoses keep temperature, why pot handles are not made of metal, and why ice crystals cool drinks. Students heat several materials (iron, water, oil, and stones) and record the temperature changes as part of the primary PhET simulation exploration exercise. In addition to analyzing the function of specific heat, experimental data is utilized to differentiate between the concepts of temperature (degree of heat) and heat (energy transfer). Worksheets, conversation observations, reflective journals, and contextual essay assessments that gauge conceptual comprehension, formula application, and critical thinking abilities are all part of the entire assessment plan.

According to (Ratnasari et al., 2025), three primary tactics that align with deep learning principles are used to operationalize the integration of deep learning concepts in this module. (1) reflective questions at the conclusion of each learning cycle that prompt students to consider presumptions and connect ideas to personal experiences; (2) data analysis tasks from PhET simulations that call for scientific inference, like comparing temperature increases of different materials to comprehend the function of specific heat; and (3) enrichment based contextual projects, like creating thermal insulators out of recycled materials or suggesting energy efficient home designs, which make it easier to apply concepts in practical settings. This method continuously changes the emphasis of learning from memory to deep comprehension, conceptual connections, and knowledge transfer all of which are key elements of deep learning.

Specific student-centered activities combined with PhET simulations operationalize each phase of the PBL paradigm. During the problem orientation phase, for example, students are asked, " *Do you know why metal spoons get hot faster than wooden spoons.?"* This inquiry causes cognitive dissonance regarding heat transport mechanisms and stimulates past knowledge. Using the PhET "Energy Forms and Changes" simulation, students collaborate to investigate how various materials (such as iron, water, oil, and brick) react to thermal energy during the group inquiry phase. In order to encourage thoughtful data interpretation and conceptual knowledge of specific heat capacity, they monitor temperature changes, compare ΔT values, and examine particle behavior. Students share their findings, engage in debate, and consider whether their initial hypotheses are consistent with the experimental outcomes during the presentation and reflection phases. These methodical procedures guarantee that PBL is closely related to critical thinking and scientific investigation rather than just being procedural. Figure 2 below illustrates how this five-stage PBL syntax is used.

Figure 2. Problem-Based Learning Syntax in the Temperature and Heat Module

4.2 Module Validity Results by Experts

Table 3. Overview of the results from the validation computation of Aiken's V value

Item	Dimension Indicator	Rater 1	Rater 2	Rater 3	S1	S2	S3	$\sum s$	V	Judgement
1	Content Suitability	5	5	5	4	4	4	12	1.00	Very Valid
2		5	5	5	4	4	4	12	1.00	Very Valid
3		4	5	5	3	4	4	11	0.92	Very Valid
4		5	5	5	4	4	4	12	1.00	Very Valid
5		5	5	5	4	4	4	12	1.00	Very Valid
6	Presentation and Learning Strategy	5	5	5	4	4	4	12	1.00	Very Valid
7		5	5	5	4	4	4	12	1.00	Very Valid
8		5	5	5	4	4	4	12	1.00	Very Valid
9		5	5	5	4	4	4	12	1.00	Very Valid
10		5	5	4	4	4	3	11	0.92	Very Valid
11	Graphics and Design	4	5	4	3	4	3	10	0.83	Very Valid
12		5	4	4	4	3	3	10	0.83	Very Valid
13		5	5	5	4	4	4	12	1.00	Very Valid
14	Learning Approach (PBL)	5	5	5	4	4	4	12	1.00	Very Valid
15		4	5	5	3	4	4	11	0.92	Very Valid
16		5	5	5	4	4	4	12	1.00	Very Valid
17	Assessment	5	5	5	4	4	4	12	1.00	Very Valid
18		5	5	5	4	4	4	12	1.00	Very Valid
19		5	5	5	4	4	4	12	1.00	Very Valid
20	Relevance to Student Characteristics	5	5	5	4	4	4	12	1.00	Very Valid
21		5	4	5	4	3	4	11	0.92	Very Valid
22		4	5	5	3	4	4	11	0.92	Very Valid

Based on the calculation of Aiken's V coefficient in Table 3, all 22 module indicators obtained V values ranging from 0.83 to 1.00. This range meets the criteria for highest validity. These findings confirm that the module has met technical feasibility standards from three expert perspectives. In addition to being confirmatory, the three experts' validation procedure produced significant revision inputs that were put into practice before the small-group study. Significant changes included: (1) improving the Student Worksheet's instructions, which were judged to be insufficiently operational and in need of more precise procedural guidance; (2) adjusting the background colour contrast of the module to make the text easier to read and lessen visual fatigue; and (3) adding contextual examples to the presentation of important concepts to increase clarity and relevance.

All five indicators in this dimension met validity criteria with coefficients between 0.92 and 1.00. It was determined that the incorporation of the PhET Energy Forms and Changes simulation was successful in depicting abstract thermal phenomena including heat energy transfer and specific heat capacity. V scores varied between 0.92 and 1.00 in the learning approach and presentation dimension. This illustrates the methodical and contextual architecture of the five-stage PBL syntax. Every step include leading questions that pique students' interest and encourage cognitive engagement in addition to adhering to the PBL procedural structure. V coefficients for the media and graphics dimensions ranged from 0.83 to 1.00. Visual ergonomics principles have been taken into consideration in the module's layout, typography choice, and illustration use to reduce unnecessary cognitive load and free up students' attention for processing conceptual material.

The three validators gave each indicator a maximum score of five in the assessment and student characteristics relevant aspects. The assessment tools, which include student worksheets, reflective journals, and contextual essay tests, were created with the goal of fostering critical thinking abilities in mind. Additionally, the lesson has integrated locally relevant situations and considered the past knowledge of Grade XI MIPA students. It is important to note that expert validity does not represent actual data of enhanced critical thinking abilities; rather, it merely represents the module's theoretical viability as a requirement for implementation. Because this study's developmental scope is restricted to the Define, Design, and Develop stages of the 4-D model, it was unable to conduct field trials with experimental designs that directly evaluate changes in cognitive capacities, which is necessary for claims regarding learning efficacy. However, the remarkably high validity results guarantee that the module is prepared to move on to the limited trial phase, which will gauge its applicability and student acceptance in real-world learning environments.

4.3 Practical Results of the Module by Students

Table 4. Results of Student Responses to PBL-Based Teaching Modules

Indicator	Score	Maximum Score	Score (%)	Category
Ease of use	127	150	84.66	Practical
Media presentation standards	45	50	90	Very Practical
Understanding of material	83	100	83	Practical
Critical thinking skills	88	100	88	Very Practical
Use of language	83	100	83	Practical
Media design	42	50	84	Practical

Ten Grade XI MIPA students participated in a small-group testing. The results showed HEOS percentages ranging from 83% to 90%, which classified the module as Practical to Very Practical for all six parameters (Table 4). Media presentation standards (90%) and critical thinking abilities (88%) received the highest results, while the Practical category included ease of use (84.66%), media design (84%), comprehension of the content (83%), and language use (83%). According to these findings, students thought the module was easy to use, aesthetically pleasing, and intellectually stimulating.

Students successfully completed the following tasks during the trial: (1) independently operated the PhET Energy Forms and Changes simulation controls; (2) entered the ΔT values for the four materials (brick, water, oil, and iron) in worksheet tables; and (3) developed preliminary hypotheses regarding specific heat capacity based on patterns in the data. Nevertheless, during think aloud procedures, two technical terms "thermal equilibrium" and "heat flux" were found to be difficult to understand. In response to this criticism, the final module version included glossary boxes with simpler definitions and common analogies for both concepts.

It is crucial to emphasize that practicality does not equate to learning effectiveness. While students found the module usable and engaging, this trial measured only usability not actual improvement in critical thinking skills. The absence of pretest-posttest instruments or a control group means that claims about "enhancing critical thinking" remain theoretical. Furthermore, the small sample size ($n = 10$) from a single school in South Sumatra limits the generalizability of findings. These constraints align with the study's developmental scope, which was restricted to the Define, Design, and Develop phases of the 4-D model.

4.4 Pedagogical Implications and Relevance to the Merdeka Curriculum

The emphasis of this course is not on the technical or practical aspects of teaching, but rather on the ability to construct an epistemological relationship between students, physical concepts, and real-world situations. Through the integration of Problem-Based Learning (PBL) as a pedagogical tool, the virtual PhET practice as a cognitive tool to visualize abstract phenomena, and the deep learning philosophy as a learning philosophy that encourages comprehension, conceptual understanding, and knowledge transfer, this method systematically transforms students' passive information consumption into active participation in the process of knowledge construction. Through research based on authentic problems, students not only learn about the relationship between temperature and heat as a formula, but also develop a conceptual understanding of thermal transfer energy as a component of everyday physical reality. This method aligns with the Pancasila Student Profile, which calls for critical, creative, and reflective thinking abilities, as well as the requirements of the Merdeka Curriculum, specifically Phase F Learning Outcomes, which highlight the capacity to evaluate and apply scientific concepts in practical settings. In order to implement this module, the teacher's role must change from instructor to facilitator, capable of directing data-based exploration of PhET simulations, guiding reflective discussions, and examining students' scientific arguments through authentic assessments like reflective journals and evidence-based presentations.

5. CONCLUSION

This project created a temperature and heat physics teaching module using Problem-Based Learning (PBL) in conjunction with PhET virtual simulations and deep learning concepts. The module was classified as Very Valid after expert validation produced Aiken's V coefficients that ranged from 0.83 to 1.00 for each of the 22 indicators. Ten student small group tests yielded HEOS percentages ranging from 83% to 90%, indicating that the curriculum was Practical to Very Practical in terms of six usability metrics. However, learning efficacy is not reflected in these findings; rather, they simply represent theoretical feasibility (validity) and usability (practicality). Because there were no pretest-posttest tools or control groups, and the study only included 10 students from one South Sumatra school, it was unable to assess real progress in critical thinking abilities. To empirically evaluate the module's impact across various school contexts, future research should apply the Disseminate phase of the 4-D model employing quasi-experimental designs (e.g., pretest-posttest control group) with Ennis's critical thinking rubric.

ACKNOWLEDGMENTS

The authors would like to sincerely thank the professional validators for their insightful comments and helpful recommendations, which greatly improved this module's technical quality, pedagogical soundness, and scientific accuracy. We sincerely thank the seasoned physics instructors who took part in the validation process for contributing their expert knowledge and real-world viewpoints on classroom application. Their knowledge was essential in ensuring that the module was in line with both curriculum requirements and actual teaching difficulties. We also want to express our sincere gratitude to the students who enthusiastically took part in the small-group trial. Their candid answers and careful analysis for assessing the usefulness and ease of use of the module. Their input was crucial in improving the overall student experience, the efficacy of PhET integrated assignments, and the clarity of instructions.

REFERENCES

Abadi, A., Novalia, I., Nazwa, M., & Angelica, R. (2025). *Analisis Penggunaan Phet Simulation dalam Meningkatkan Pemahaman Konsep Suhu dan Kalor: A Review Literatur*. *13*. https://doi.org/10.9644/sindoro.v3i9.252

Abdullah, E. N. W., Sutrio, Ayub, S., & Doyan, A. (2024). Pengembangan Perangkat Model Problem Based Learning dengan Google Classroom untuk Meningkatkan Penguasaan Konsep Suhu dan Kalor Peserta Didik. *Jurnal Penelitian Pendidikan IPA*, *10*(6), 2906–2915. https://doi.org/10.29303/jppipa.v10i6.5205

Adhelacahya, K., Sukarmin, S., & Sarwanto, S. (2023). Impact of Problem-Based Learning Electronics Module Integrated with STEM on Students' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 4869–4878. https://doi.org/10.29303/jppipa.v9i7.3931

Agus Kurniawan, D., Putri Wirman, R., Wulan Dari, R., & Yuhanis, E. (2020). Description of Student Science Process Skills on Temperature and Heat Practicum. *Jurnal Penelitian Dan Evaluasi Pendidikan*, *24*(1), 88–101. https://doi.org/https://doi.org/10.21831/pep.v24i1.31194

Anggreani, H., Harjito, Sumarni, W., & Nurhayati, S. (2025). Pengaruh Penerapan PBL Bervisi SETS dengan Kerangka Kerja Paul-Elder Berbantuan Video Pembelajaran dalam Meningkatkan Keterampilan Berpikir Kritis Siswa. *Jurnal Inovasi Pendidikan Kimia*.

Arifah, N., Kadir, F., & Nuroso, H. (2021). Hubungan Antara Model Pembelajaran Problem Based Learning dengan Kemampuan Berpikir Kritis pada Pembelajaran Fisika Siswa. *Karst: Jurnal Pendidikan Fisika Dan Terapannya*, *4*. https://doi.org/10.46918/karst.v4i1.946

Astari, M., Palloan, P., Mutahharah, D., Analisis, H., Fisika, M., & Suhu, M. (2022). Analisis Miskonsepsi Fisika Materi Suhu dan Kalor Menggunakan Three Tier Diagnostic Test di Masa Pandemi Covid-19 di SMAN 1 Pinrang. In *Jurnal Sains dan Pendidikan Fisika (JSPF) Jilid* (Vol. 18, Number 3).

Astra, I. M., Sasmito, R. N., & Wibowo, F. C. (2019). Improvement of students' critical thinking ability through problem-based learning (PBL) model class XI MIPA 3 on temperature and heat material. *AIP Conference Proceedings*, *2169*. https://doi.org/10.1063/1.5132648

Darmawati, Y., & Mustadi, A. (2023). The Effect of Problem-Based Learning on the Critical Thinking Skills of Elementary School Students. *Jurnal Prima Edukasia*, *11*(2), 142–151. https://doi.org/10.21831/jpe.v11i2.55620

Hafild, M. N. R., Abdurahman, & Yulianti, D. (2025). Meningkatkan Kemampuan Komputasi Siswa Dengan Model Pembelajaran Berbasis STEAM PJBL. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, *10*(1).

Hudaya Salsabila, A., Iriani, T., & Sri Handoyo, S. (2023). Penerapan Model 4D Dalam Pengembangan Video Pembelajaran Pada Keterampilan Mengelola Kelas. In *Jurnal Pendidikan West Science* (Vol. 01, Number 08).

Kapul, M., Lantik, V., & Astiti, K. A. (2023). Analisis Miskonsepsi Siswa dan Alternatif Remediasinya pada Konsep Suhu dan Kalor. In *Jurnal Pendidikan dan Pembelajaran IPA Indonesia* (Vol. 13, Number 1).

Lubis, R. S., & Sabani. (2023). Analisis Keterampilan Berpikir Kritis Siswa SMA pada Materi Suhu dan Kalor. *Jurnal Inovasi Pembelajaran Fisika*. https://doi.org/10.24014/jnsi.v4i2.11445

Mahmud, A. P. M., Yusuf, M., Abdjul, T., Pikoli, M., Ntobuo, N. E., & Paramata, D. D. (2024). Application of the PBL Model on Temperature and Heat Concepts to Student Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 4333–4341. https://doi.org/10.29303/jppipa.v10i7.8002

Nurjanah, S., Istiyono, E., Widihastuti, W., Iqbal, M., & Kamal, S. (2023). The Application of Aiken's V Method for Evaluating the Content Validity of Instruments that Measure the Implementation of Formative Assessments. *Journal of Research and Educational Research Evaluation*, *12*(2), 2023–2125. http://journal.unnes.ac.id/sju/index.php/jere

Otoluwa, S. M., Uloli, R., Abdjul, T., Mursalin, Odja, A. H., & Ntobuo, N. E. (2024). The Influence of the PBL Model to Student Learning Outcomes on Heat and its Transfer Concepts. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 4357–4363. https://doi.org/10.29303/jppipa.v10i7.8003

Permatasari, A. D., & Satianingsih, R. (2025). Pengaruh Model PBL Terhadap Kemampuan Berpikir Kritis Kelas IV Sekolah Dasar. *Jurnal Ilmiah Pendidikan Dasar*, (1).

Pratiwi, S., Wiyono, K., & Zulherman, Z. (2020). Pengembangan E-Learning Materi Hukum Newton Untuk Mengembangkan Keterampilan Berpikir Kritis Siswa Sekolah Menengah Atas. *Jurnal Pendidikan Fisika*, *8*(2), 172. https://doi.org/10.24127/jpf.v8i2.2780

Putri, S. J., & Prahani, B. K. (2024). Enhancing students' critical thinking skills through mobile technology: An analysis of problem-based learning implementation in heat material instruction. *Advances in Mobile Learning Educational Research*, *5*(1), 1242–1253. https://doi.org/10.25082/amler.2025.01.001

Rahmadita, N., Mubarok, H., & Prahani, B. K. (2021). Profile of Problem-based Learning (PBL) Model Assisted by PhET to Improve Critical Thinking Skills of High School Students in Dynamic Electrical Materials. *Jurnal Penelitian Pendidikan IPA*, *7*(4), 617–624. https://doi.org/10.29303/jppipa.v7i4.799

Ratnasari, Nikmah Nurvicalesti, & Ami Sulistia Wati. (2025). Implementasi Pembelajaran Mendalam terhadap Kemampuan Berpikir Kritis Matematis Siswa. *Algoritma : Jurnal Matematika, Ilmu Pengetahuan Alam, Kebumian Dan Angkasa*, *3*(4), 43–50. https://doi.org/10.62383/algoritma.v3i4.576

Reyza Arief Taqwa, M., & Suyudi, A. (2020). Analisis Miskonsepsi Topik Suhu dan Kalor Mahasiswa Pendidikan Fisika Universitas Negeri Malang. *Briliant: Jurnal Riset Dan Konseptual*. https://doi.org/10.28926/briliant

Rizki, M. E., Albertus, Lesmono, D., & Supriadi, B. (2019). Analisis Kemampuan Berpikir Kritis Siswa Dalam Menyelesaikan Open-Ended Question pada Materi Fluida Statis di SMA. *Jurnal Pembelajaran Fisika*, (4). https://doi.org/10.19184/jpf.v8i1.11672

Safitri, R., Hadi, S., & Widiasih, W. (2023). Effect of the Problem Based Learning Model on the Students Motivation and Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 7310–7316. https://doi.org/10.29303/jppipa.v9i9.4772

Sajiwo, W. T., Sarwanto, S., & Ashadi, A. (2019). Kelayakan Modul IPA SMP/MTS Berbasis Problem Based Learning pada Materi Suhu dan Pemuaian. *INKUIRI: Jurnal Pendidikan IPA*, *8*(2), 129. https://doi.org/10.20961/inkuiri.v8i2.37750

Serevina, V., & Sari, I. J. (2018a). Development of E-Module Based on Problem Based Learning (PBL) on Heat and Temperature to Improve Student's Science Process Skill. In *TOJET: The Turkish Online Journal of Educational Technology* (Vol. 17, Number 3).

Serevina, V., & Sari, I. J. (2018b). Development of E-Module Based on Problem Based Learning (PBL) on Heat and Temperature to Improve Student's Science Process Skill. In *TOJET: The Turkish Online Journal of Educational Technology* (Vol. 17, Number 3).

Sujanem, R., & Putu Suwindra, I. N. (2023). Problem Based Interactive Physics E-Module in Physics Learning Through Blended PBL to Enhance Students' Critical Thinking Skills. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 135–145. https://doi.org/10.15294/jpii.v12i1.39971

Sundari, P. D., & Sarkity, D. (2021). Keterampilan Berpikir Kritis Siswa SMA pada Materi Suhu dan Kalor dalam Pembelajaran Fisika. *Journal of Natural Science and Integration*, *4*(2), 149. https://doi.org/10.24014/jnsi.v4i2.11445

Suryadi, S., Sundaryono, A., & Nurhamidah, N. (2019). Pengembangan Modul KOBA dengan Model 4-D untuk Meningkatkan Kemampuan Berpikir Kreatif Mahasiswa. *PENDIPA Journal of Science Education*, *3*(2), 95–99. https://doi.org/10.33369/pendipa.v3i2.7700

Taufik, Nurtamam, M. E., Dewanto, & Santosa, T. A. (2025). The Effectiveness of Deep Learning based PjBL on Student's Scientific and Critical Thinking Skills at Indonesia. *Jurnal Penelitian Pendidikan IPA*, *11*(9), 228–236. https://doi.org/10.29303/jppipa.v11i9.12857

Veronika Tiara, Ninawati Ninawati, Fransiska Liska, Rabiatul Alya, & Yusawinur Barella. (2024). Menggali Potensi Problem Based Learning: Definisi, Sintaks, Dan Contoh Nyata. *SOSIAL: Jurnal Ilmiah Pendidikan IPS*, *2*(2), 121–128. https://doi.org/10.62383/sosial.v2i2.153

Wiyono, K. (2015). Pengembangan Model Pembelajaran Fisika Berbasis ICT pada Implementasi Kurikulum 2013. *Jurnal Inovasi Dan Pembelajaran Fisika*, *2*(2).

Yovianda, F., Juliani, R., & Amri Hasibuan, K. (2019). Application of Problem Based Learning (PBL) to Increasing Student Activity in the Subject Matter of Temperature and Heat. *Journal of Physics: Conference Series*, *1317*(1). https://doi.org/10.1088/1742-6596/1317/1/012157

Yuliana, I., Artawan, P., & Heny, A. P. (2023). Profil Miskonsepsi Siswa pada Materi Suhu dan Kalor. *Jurnal Penelitian Dan Ilmu Pendidikan*, *4*(4), 1161–1166. https://doi.org/10.55681/nusra.v4i4.1763

Zamsiswaya, Sawaluddin, & Sihombing, B. (2024). Model Pengembangan 4D (Define, Design, Develop, dan Disseminate) dalam Pembelajaran Pendidikan Islam. *Journal of Islamic Education El Madani*, *4*(1). https://doi.org/https://doi.org/10.55438/jiee.v4i1.135