Primary: Jurnal Pendidikan Guru Sekolah Dasar
journal homepage: https://primary.ejournal.unri.ac.id/
contents lists available at SINTA and DOAJ

Vol. 14 No. 6 (2025): December
http://dx.doi.org/10.33578/jpfkip.v14i6.1011-1025

Cultivating critical thinking: the development and impact of PBL worksheets in elementary science learning

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Article info

Keywords:
Student worksheets, problem-based learning (PBL), critical thinking, science learning

Abstract

This study was motivated by the low level of critical thinking skills among primary school students in science learning, which requires innovation in teaching materials. The purpose of this study was to develop and test the effectiveness of Student Worksheets based on Problem-Based Learning (PBL) to improve critical thinking skills in the subject of 'Light and Its Properties'. Research and Development (R&D) were conducted using the ADDIE model and a quasi-experimental design. The research subjects consisted of 52 fifth-grade elementary school students, divided into experimental and control groups. The research instruments included essay tests, observation sheets, and assessment rubrics. Expert validation results showed that the Student Worksheet was deemed highly valid in terms of media (4.58), valid in terms of material (4.44), and valid in terms of language (4.46). The effectiveness test results proved that the experimental class experienced a significant increase in all critical thinking indicators (total score of 20.9) compared to the control class (14.1). Statistical tests ($p < 0.001$) and effect sizes (Cohen's $d = 1.65$-2.45) confirmed that this improvement was statistically significant and had a large effect. It was concluded that PBL-based Student Worksheets were effective in fostering critical thinking skills in primary school students and were recommended for use in science learning.

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DOI: http://dx.doi.org/10.33578/jpfkip.v14i6.1011-1025
Received 13 October 2025; Received in revised form 9 November 2025; Accepted 19 November 2025; Available online 5 December 2025
e-ISSN 2598-5949 | p-ISSN 2303-1514

1. Introduction

The ever-evolving demands of the 21st Century have fundamentally changed educational priorities, shifting from rote memorisation to the development of higher-order cognitive skills (Dinelti Fitria et al., 2023; Parmini et al., 2023; Rohman et al., 2024). Critical thinking skills have become a key foundation, empowering individuals to analyse information, evaluate evidence,

and solve complex problems – skills that are irreplaceable for scientific literacy (Trilling & Fadel, 2009). This need is further emphasized by the skills required in the 21st-century learning process, which necessitate students mastering the 4Cs: Critical Thinking, Communication, Collaboration, and Creativity (Cahyaningsih & Nahdi, 2021; Julianto et al., 2023; Kasuga et al., 2022; Rohman et al., 2023). International assessments, such as the Programme for International Student Assessment (PISA), consistently highlight the global focus on these skills, but show that students in many countries, including Indonesia, struggle with tasks that require deep analytical reasoning and conceptual understanding (OECD, 2022). This gap underscores the urgent need for pedagogical innovation, particularly in primary education, where the fundamental dispositions for scientific inquiry and critical analysis are formed (Jayanto et al., 2024; Melinda et al., 2025; Pramudiyanti et al., 2023; Rohman F et al., 2023).

This competency gap is particularly evident in science education, where critical thinking serves as the basis for scientific inquiry (Renny Dwijayanti et al., 2023; Syahmel & Jumadi, 2019). This ability enables students to move beyond memorising facts to understanding the process of analysing, investigating, and drawing evidence-based conclusions, which are the actual characteristics of science (Care, 2018; Huang et al., 2019; Trilling & Fadel, 2009). However, the implementation of critical thinking objectives in daily classroom practice remains a serious obstacle in Indonesian primary schools. Science teaching in the integrated Natural and Social Sciences subject is still often dominated by a teacher-centred and textbook-oriented approach. This paradigm provides limited opportunities for students to engage in authentic discovery learning, which is necessary for developing critical thinking (Rohman et al., 2023).

Initial observations in class five at SD N 2 Kupang Teba, Teluk Betung Utara District, Bandar Lampung City, Lampung Province confirmed this problem by showing students' significant difficulties in critical thinking skills, such as formulating questions that can be investigated and evaluating arguments. The main contributing factors include a lack of quality and structured learning resources that actively guide students through critical investigation processes. The results of the researcher's literature study found that Problem-Based Learning (PBL) emerged as a potential pedagogical model to address these gaps and problems (Alrahlah, 2016; Hawamdeh & Adamu, 2021; Melinda et al., 2025; Pramudiyanti et al., 2023; Reed et al., 2021; Rohman et al., 2024; Wandira et al., 2024). As a student-centred learning model that utilises structured real-world problems, PBL offers students the opportunity to conduct investigations, collaborate, and engage in independent learning (Kasuga et al., 2022; Rohman et al., 2025; Setiadi et al., 2025).

The success of PBL implementation for primary school students' learning depends on the availability of appropriate learning scaffolding to support students' developing cognitive abilities (Choo et al., 2011; Hmelo-Silver et al., 2007; Maksić & Jošić, 2021). The strategic design of teaching materials, particularly Student Worksheets, is an important element in this study. Worksheets in the PBL approach need to function as structured guides that facilitate the problem-solving process explicitly, rather than simply being a collection of exercises (Murni et al., 2025; Setiadi et al., 2025). Although the development of PBL-based worksheets has been studied in various educational contexts, significant research gaps remain. Most previous studies have focused on the feasibility, validity, and practicality of the developed materials, while strong empirical evidence regarding the causal impact on the multifaceted dimensions of critical thinking skills in basic science is still limited (Rohman et al., 2025).

This study aims to fill this gap through the systematic development and empirical evaluation of PBL-based worksheets for the topic 'Light and Its Properties' in the Grade 5 Natural and Social Sciences curriculum. This study not only designs valid and practical learning tools but also rigorously measures their effectiveness in improving students' critical thinking skills. Using a

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quasi-experimental design, the study seeks to provide convincing evidence of the impact of strategically designed PBL materials, while offering practical and innovative solutions to the challenges of developing critical thinking in basic science education. These findings are expected to significantly contribute to the enrichment of the repertoire of effective teaching materials and inform pedagogical practices aligned with the demands of 21st-century learning.

2. Method

2.1 Research design

This study utilised a Research and Development (R&D) approach with a quasi-experimental design at the product effectiveness testing stage. The development framework referred to the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation, which provided a systematic process for developing PBL-based Student Worksheets. To test the effectiveness of the intervention, a non-equivalent control group design was employed, involving an experimental class that utilized the developed Student Worksheets and a control class that received conventional instruction.

2.2 Research subject

The study was conducted at SD N 2 Kupang Teba, Teluk Betung Utara District, Bandar Lampung City, Lampung Province, involving 52 fifth-grade students divided into two groups: an experimental group and a control group. Class V_A (n = 27) was designated as the experimental class, which received a learning intervention using PBL-based Student Worksheets, while Class V_B (n = 25) served as the control class, continuing regular learning with textbooks and existing materials. This sample selection took into account the naturally formed class conditions to minimise disruption to the school's academic schedule.

2.3 Development and intervention procedures

The development of PBL-based Student Worksheets follows the operational stages of the ADDIE instructional design model, which is implemented technically as follows:

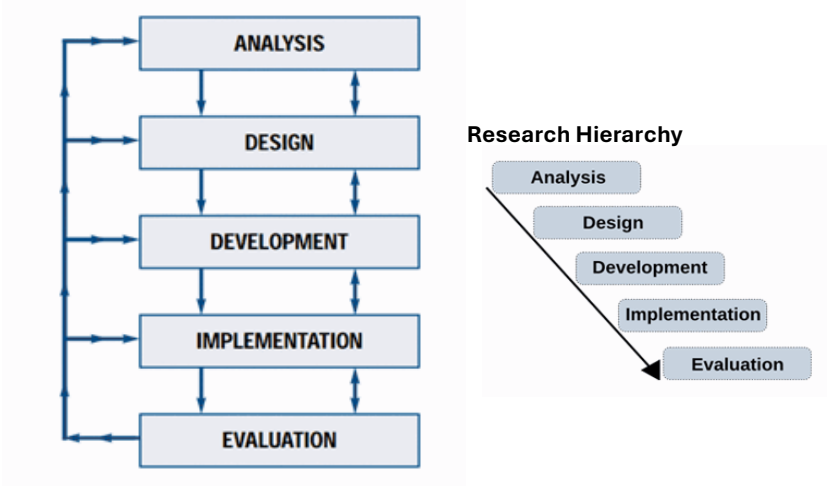

Figure 1. Research implementation stage (Branch, 2010)

The Analysis stage conducts a comprehensive analysis through: (1) Curriculum analysis of the Merdeka Curriculum document to identify Learning Outcomes and Learning Objectives for

Grade 5 Natural and Social Sciences in the subject 'Light and Its Properties'; (2) Learner analysis through systematic observation and semi-structured interviews with teachers to identify learning styles and initial competency levels, which revealed gaps in critical thinking skills, particularly in the aspects of providing further explanations and drawing conclusions; and (3) Context analysis of school facilities and available learning resources.

The Design stage adopts modern instructional design principles (Gawlik-Kobylinska, 2018) which are realised in: (1) the formulation of learning objective specifications using the ABCD framework (Audience, Behaviour, Condition, Degree); (2) mapping content that integrates Natural and Social Science concepts with PBL syntax (Setiadi et al., 2025) and critical thinking ability indicators adapted from the framework (Ennis, 2011), covering five main dimensions: (a) providing simple explanations (including question focus, question analysis, and answering questions), (b) building basic skills (covering consideration of source credibility and observation reports), (c) organising strategies and tactics, (d) providing further explanations (covering definition of terms and identification of assumptions), and (e) concluding (covering deduction, induction, and making value judgements); (3) designing a prototype Student Worksheet consisting of an identity page, learning introduction, conceptual framework, contextual problem scenarios, guided investigation activities in accordance with PBL stages, and a critical thinking assessment rubric that refers to the five indicators; and (4) the storyboarding process with the application of multimedia learning principles (Mayer, 2021).

The Development stage implements an iterative process (Branch, 2010) comprising: (1) development of Student Worksheet content that accommodates complete PBL syntax and explicitly designs activities to stimulate each critical thinking indicator, such as compiling guiding questions for the indicator 'providing simple explanations' and structured observation tasks for the indicator 'developing basic skills'; (2) production of media using graphic design software, taking into account the principles of cognitive load theory (Sweller, 2011); (3) expert validation by three experts using standardised instruments adapted from research (Pratiwi et al., 2024), and for assessing the suitability and clarity of critical thinking indicators integrated from research (Rohman et al., 2024); and (4) product revision through several improvement cycles based on expert recommendations to ensure content accuracy and pedagogical effectiveness.

The Implementation stage follows the educational intervention implementation protocol (Arici et al., 2019; Cohen et al., 2007) through: (1) teacher briefing to ensure a deep understanding of the PBL approach and how to assess each indicator of critical thinking in students during the learning process; (2) trials in experimental classes during five meetings (@2×35 minutes) with a planned structure; and (3) process monitoring using structured observation sheets designed to document the emergence and development of the five critical thinking indicators in students, while ensuring fidelity of implementation.

The Evaluation stage included formative evaluation during each ADDIE phase through expert review, individual testing, and small group evaluation, as well as summative evaluation through quantitative measurement of critical thinking improvement using pretest-posttest comparisons, qualitative analysis of student and teacher feedback, and statistical analysis of learning outcome differences between the experimental and control groups. The final product is then refined based on implementation findings to produce a final version of the Student Worksheet that is sustainable and measurable.

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3. Method

This study utilised three main instruments to measure the effectiveness of PBL-based Student Worksheets in improving students' critical thinking skills. These instruments consisted of an essay-based critical thinking test, a systematic observation sheet, and an analytical assessment rubric. The essay test was developed based on five crucial thinking indicators adapted from the framework (Ennis, 2011), which include the ability to provide simple explanations, build basic skills, organise strategies and tactics, provide further explanations, and draw conclusions. Each question item was specifically designed to trigger the manifestation of the predetermined sub-indicators. The test instrument underwent content validation by two science education experts and reliability testing with a Cronbach's Alpha coefficient of 0.86, indicating an adequate level of internal consistency.

The structured observation sheet serves as a complement to quantitative data by documenting the frequency and quality of critical thinking indicators during the learning process (Creswell & Creswell, 2018). The analytical assessment rubric employs a 4-point Likert scale to evaluate student performance on each sub-indicator objectively. All of these instruments underwent a validation process through expert assessment and limited trials before being implemented in the main study. This validation process ensures the accuracy of the construct and consistency of measurement in comprehensively capturing the growth of students' critical thinking skills.

4. Results

4.1 Analysis stage results

The results of the needs analysis are as follows: Curriculum Analysis: It was found that the Learning Outcomes and Learning Objectives in the ‘Light and Its Properties’ material in the Merdeka Curriculum are highly relevant to the development of critical thinking skills, but the existing teaching materials do not explicitly facilitate this.

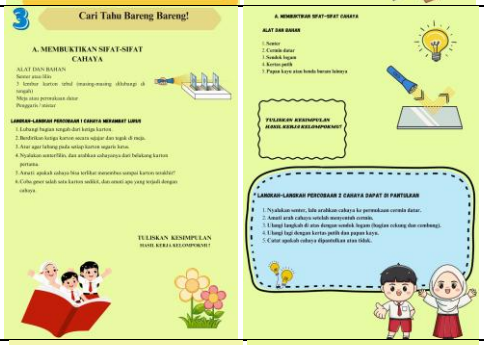
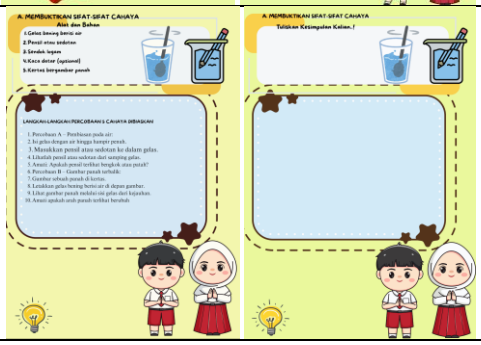
Student Analysis: Observations and interviews with teachers revealed that fifth-grade students experience significant difficulties in aspects of critical thinking, particularly in providing further explanations (such as identifying assumptions) and drawing conclusions (performing deductive and inductive reasoning). Context Analysis: The school has adequate basic facilities, but lacks structured learning resources that can guide students through the process of independent investigation and problem solving.

4.2 Design stage results

Based on the analysis results, a prototype Student Worksheet was designed with the following specifications: Structure: The Student Worksheet fully integrates PBL syntax (from problem orientation to presentation of results) into learning activities. Each activity in the Student Worksheet is specifically designed to improve one or more critical thinking skill indicators, as outlined in the framework (Ennis, 2011). For example, the formulation of investigative questions is designed to train the indicator "providing simple explanations". Design Principles: The Student Worksheet is created by applying multimedia learning principles and cognitive load theory to ensure clarity and ease of use (Sweller, 2011). The storyboard for the PBL-based student worksheet on the material "Light and Its Properties" is shown in Table 1.

[e-**ISSN 2598-5949** | p-**ISSN 2303-1514**]

Table 1. The storyboard student worksheet based on PBL on the subject of light and its properties

No	Subsection	Display	Description
1.	Cover		Cover page of the student worksheet containing illustrations of the material. This cover page includes the title of the material and illustrations about light and its properties for fifth-grade primary school students. Instructions for using the student worksheet provide positive affirmation from the teacher to the students before learning.
2.	Problem orientation; Organising students for learning.		In the first part, students are invited to observe and analyse contextual phenomena related to the material. In the second part, students are guided to discuss the results of their analysis of the issues.
3.	Guiding group investigations		In the third part, students gather relevant information, conduct simple experiments, and solve problems in groups.
4.	Analysing and evaluating problem-solving processes		Students reflect on and evaluate the investigation process and provide feedback on the solutions found.

4.3 Development stage results

Before being tested on students, the prototype Student Worksheet was first evaluated for feasibility to ensure its effectiveness. It was then implemented in the classroom learning process, and the validation process aimed to ensure its quality from various aspects. Figure 2 shows the assessment results obtained from the subject matter experts.

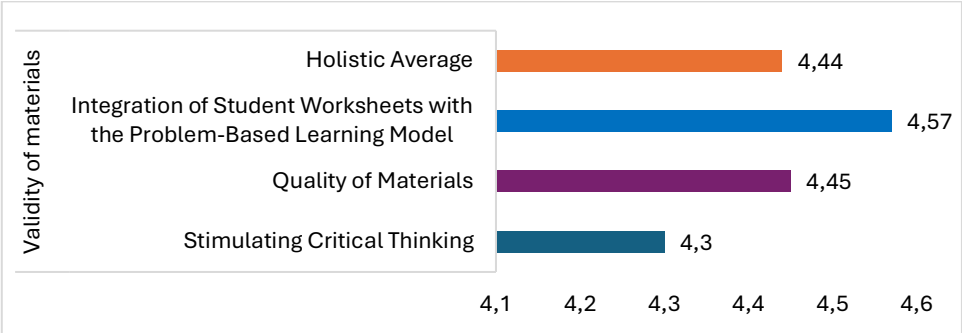


Figure 2. Material aspect validation test results

The results of the material validation show that the PBL-based Student Worksheets that were developed have met the overall validity criteria (score of 4.44). Specifically, the aspect of integration with the PBL model achieved the category of Highly Valid (4.57), indicating that the syntax and principles of PBL have been well internalised in the design of the Student Worksheets. This is in line with research (Chin & Chia, 2004; Murni et al., 2025; Rohman et al., 2023; Şendağ & Ferhan Odabaşı, 2009) which emphasises that the success of PBL is highly dependent on the alignment between contextual problems and learning activities.

The material quality component (4.45) and critical thinking stimulation (4.30) are also in the Valid category, indicating that the scientific content is accurate and the learning activities have been designed to trigger analytical and evaluation skills. However, the relatively lower critical thinking stimulation score indicates a need to strengthen the scaffolding of more in-depth guiding questions, as recommended by (Hmelo-Silver et al., 2007). The second feasibility test was conducted to assess the feasibility of the media aspect, as illustrated in Figure 3.

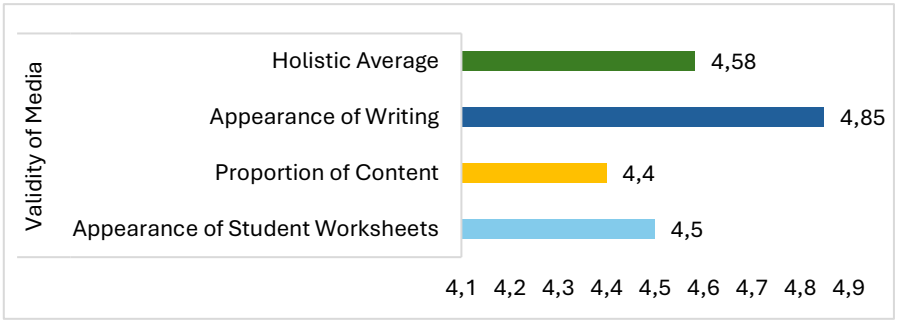


Figure 3. Media aspect validation test results

Media validation yielded an overall score of Very Valid (4.58), with the text display and appearance of the Student Worksheet components achieving a nearly perfect score (4.85). This reflects the successful application of multimedia learning design principles (Mayer, 2021), particularly in terms of: 1) Optimal text readability; 2) Balanced and proportional layout; and 3) Visual organisation that supports information processing.

The content proportion value, which is also highly valid (4.58), indicates the right balance between text and visual elements, thereby avoiding cognitive overload as described by Sweller (2011). The final feasibility test was conducted to assess the feasibility of the language aspect, as illustrated in Figure 4.

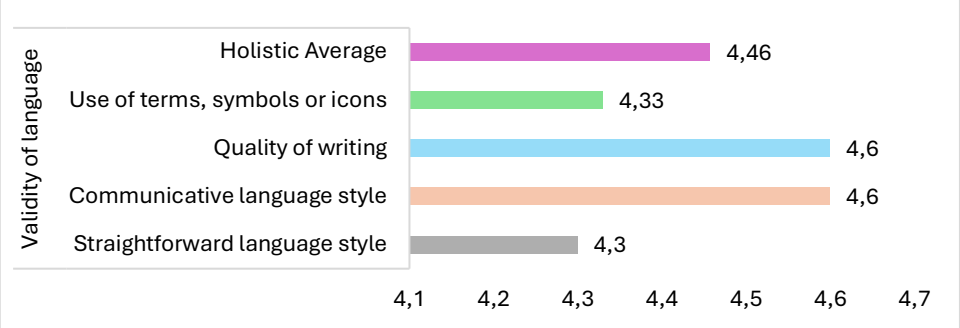


Figure 4. Language aspect validation test results

The linguistic aspect received an overall Valid score (4.46), with two main components reaching the Highly Valid category. The communicative and straightforward style of language (4.60 each) indicates that the Student Worksheet has used language that is appropriate for the cognitive development level of fifth-grade students, as emphasised by the principle of age-appropriate communication (Veronica et al., 2020). The components of term/icon usage (4.46) and writing quality (4.33) in the Valid category indicate that, although generally good, there is still room for improvement in terms of consistency in the use of scientific terminology and more precise sentence structure.

4.4 Implementation and evaluation stage results

The validated Student Worksheets were then implemented in learning to test their effectiveness.

4.4.1 Effectiveness test results

The implementation of PBL-based Student Worksheets has been proven to improve students' critical thinking skills significantly. The experimental class that used Student Worksheets scored substantially higher than the control class on all indicators.

Table 2. Comparison of average critical thinking skills scores

No	Indicators	Experimental Class	Control Class	Difference
1	Providing simple explanations	4.1	3.0	+1.1
2	Building basic skills	4.1	2.6	+1.5
3	Setting strategies & tactics	4.3	2.9	+1.4
4	Providing advanced explanations	4.0	2.6	+1.4
5	Concluding	4.4	3.0	+1.4
	Total Score	20.9	14.1	+6.8

Table 2 shows that the experimental class using PBL-based Student Worksheets consistently outperformed the control class in all critical thinking skill indicators, with a total score difference of +6.8. The most significant improvement was seen in the indicators' Building Basic Skills' (+1.5) and 'Developing Strategies & Tactics' (+1.4), which shows that the structured scaffolding in PBL-based Student Worksheets effectively guides students in the process of investigating and planning key components of self-regulated learning. These findings are consistent with research (Hmelo-Silver et al., 2007; Setiadi et al., 2025; Tri Santi et al., 2024) emphasising that scaffolding in PBL supports achievement by guiding student inquiry and planning. Furthermore, the significant improvement in 'Concluding' (+1.4) reflects the capacity

of Student Worksheets to facilitate evidence-based reasoning, which is the foundation of science literacy, as outlined in the framework on critical thinking (Ennis, 2011) Overall, these results provide strong evidence of the effectiveness of PBL-based Student Worksheets as a cognitive tool that significantly enhances multidisciplinary essential skills of thinking in primary school students.

4.5 Inferential statistics test results

The Independent Samples T-Test and Mann-Whitney U Test prove that the differences in all indicators are statistically significant (p-value < 0.001). The Effect Size (Cohen's d), which ranges from 1.65 to 2.45, indicates that the impact of this intervention is not only statistically significant but also very large ('Large' to 'Very Large') in practical terms.

Table 3. Hypothesis test results and effect size

No	Aspect	p Value	Effect Size (Cohen's d)
1.	Providing simple explanations	p < 0.001	2.45 (Very Large)
2.	Building basic skills	p < 0.001	1.65 (Large)
3.	Setting strategies & tactics	p < 0.001	2.39 (Very Large)
4.	Providing advanced explanations	p < 0.001	2.31 (Very Large)
5.	Concluding	p < 0.001	2.00 (Very Large)

Table 3 confirms that the improvement in critical thinking skills observed in the experimental class was not only statistically significant (p < 0.001 for all aspects) but also had a huge practical impact, as indicated by Cohen's d effect sizes ranging from 1.65 (Large) to 2.45 (Very Large). Effect sizes consistently exceeding 0.8 indicate that PBL-based Student Worksheet interventions have a much stronger influence than most educational interventions, as reported in a meta-analysis by Hattie (2008) on factors affecting student achievement. Effect sizes above 0.4 are considered desirable, while effect sizes above 1.2 are categorised as extraordinary. These findings are reinforced by research (Lakens, 2013) emphasising that effect sizes provide deeper practical meaning than statistical significance alone, and a value of d > 2.0, as found in the 'Providing Simple Explanations' aspect (2.45), indicates a very striking difference between the experimental and control groups. Thus, these results provide strong, convincing evidence of the effectiveness of PBL-based Student Worksheets in fostering critical thinking skills among primary school students.

4.6 Learning process observation results

Observational data from five implementation sessions showed striking differences in critical thinking skills, activities, and quality between the experimental class and the control class. This comparison is summarised in Table 4.

Table 4. Comparison of observation results of critical thinking skills activities

No	Critical thinking skills indicators	Karakteristik aktivitas pembelajaran	
		Experimental class	Control class
1.	Providing Simple Explanations (Focusing on questions, Analysing questions)	Students actively formulate investigative questions such as 'Why do shadows change size?' and 'How can we prove that light travels in a straight line?'.	The questions asked by students were mostly factual and closed-ended, such as 'What is the name of this property of light?' or 'What is the answer, Miss?'.

No	Critical thinking skills indicators	Karakteristik aktivitas pembelajaran	
		Experimental class	Control class
2.	Building Basic Skills (Considering the credibility of sources, Observation reports)	Students critically compare their group's observations with those of other groups and discuss why the results may differ. Students question the accuracy of the data.	Students accepted information from the teacher and textbooks without further questioning. Observation reports often copied the given examples without in-depth analysis.
3.	Organising Strategies & Tactics	There is a visible process of collaboration and planned division of tasks within the group. Students discuss investigation strategies, such as 'Let's try measuring from different angles first' before concluding.	Group activities are less structured. Students work individually or rely on one or two people who are considered the most knowledgeable.
4.	Providing Advanced Explanations (Identifying assumptions)	Students begin to identify assumptions in their arguments, such as stating, 'We assume that the light source is fixed, so if the shadow changes, it must be because of the distance.'	Students' explanations often lead directly to the final answer without mentioning the underlying assumptions or reasoning.
5.	Drawing Conclusions (Deduction and Induction)	Conclusions are drawn based on a chain of arguments derived from the collected data. For example, 'Because in 5 experiments, the light never deviated, it can be concluded that light travels in a straight line.'	Conclusions are often a restatement of definitions found in textbooks or teachers' explanations, rather than the results of their own data analysis.

Overall, observations of the learning process confirmed the quantitative data. The experimental class that used PBL Student Worksheets showed more lively and student-centred classroom dynamics. The Student Worksheets successfully functioned as scaffolding that guided students to practise each stage of critical thinking explicitly (Maksić & Jošić, 2021). Students did not just look for the 'right' answers but were involved in the process of constructing their own knowledge through contextual problems.

In contrast, in the control class, learning remained teacher-centered. Student activities primarily consisted of listening, taking notes, and completing procedural exercises. As a result, although students could answer factual questions, their ability to analyse, collaborate, and conclude independently was not optimally trained. This qualitative difference reinforces the conclusion that PBL-based Student Worksheets not only improve critical thinking scores but, more importantly, change the way students learn and think.

5. Discussion

The empirical findings of this study clearly demonstrate the effectiveness of PBL-based Student Worksheets in improving the critical thinking skills of fifth-grade students. The significant improvement observed across all five dimensions of critical thinking in the experimental group, as outlined in the results, provides strong evidence of the successful operationalisation of the PBL framework in the designed learning materials.

The most substantial improvement was observed in the students' ability to provide simple explanations (e.g., focusing and analysing questions) and organise strategies and tactics. This

can be directly attributed to the structured nature of the PBL Student Worksheet, which explicitly provides scaffolding for the inquiry process (Hmelo-Silver et al., 2007; Maksić & Jošić, 2021). The Student Worksheet guides students from problem orientation to strategy development, requiring them to formulate investigable questions and plan their approach, a core component of self-regulated learning (Martin-Requejo et al., 2023). The significant mean differences (+1.1 and +1.4) and huge effect sizes (Cohen's d = 2.45 and 2.39) for these indicators confirm the potential of structured scaffolding in eliciting complex cognitive behaviours from primary school students.

Furthermore, the notable improvement in reasoning (mean difference = +1.4) highlights the success of the Student Worksheet in guiding students through evidence-based reasoning. The iterative cycle of inquiry, data collection, and interpretation embedded in the PBL syntax allows learners to explicitly practise inductive and deductive reasoning (Rohman et al., 2025; Şendağ & Ferhan Odabaşı, 2009). These findings are consistent with the constructivist view that knowledge is constructed through experience and reflection, and that learning materials should create opportunities for this process to occur (Kurniawati et al., 2020; Yayuk & Husamah, 2020). The ability to draw valid conclusions from data is the foundation of science literacy, and its improvement here signals a shift from rote memorisation to genuine conceptual understanding.

The development of basic skills, such as assessing the credibility of sources and reporting observations, also showed significant improvement. The PBL environment, facilitated by Student Worksheets, required collaboration and peer evaluation. Learners were observed comparing results and questioning differences, which inherently fosters a critical attitude towards information. This aligns with research indicating that collaborative problem-solving environments are effective in developing the epistemic cognition necessary for evaluating claims and evidence (Schäfer et al., 2024; Van Hooijdonk et al., 2024).

Qualitative data from observations reinforce quantitative results, revealing a fundamental shift in classroom dynamics. The experimental class transitioned from a passive, teacher-centered model to an active, learner-centered learning community. Students in the experimental group were observed to engage in high-level discourse, such as identifying assumptions in fellow students' arguments and providing further explanations. This shift is critical, as it reflects not only improved test scores but a more profound change in students' cognitive habits and approaches to learning (Dalila et al., 2022; Schäfer et al., 2024). In contrast, the control group's activities remained largely procedural and fact-oriented, limiting opportunities for deep cognitive engagement.

The large effect sizes (ranging from large to very large) across all indicators are highly convincing. This indicates that the impact of the intervention is not only statistically significant but also educationally substantial. Such levels of practical significance are often sought but rarely achieved in educational interventions, especially in relatively short implementation periods (Hattie, 2012). The success of this intervention can be attributed to the rigorous development process, which employed the ADDIE model. This approach ensured that the Student Worksheets were not only theory-based but also highly practical and context-appropriate, as validated by high scores from subject matter, media, and language experts.

Overall, this discussion reinforces the claim that systematically developed PBL-based Student Worksheets serve as powerful cognitive tools. The Student Worksheets effectively bridge the gap between the theoretical promise of PBL and its practical implementation in real-world basic science classrooms, leading to significant improvements in multidimensional critical thinking skills.

[e-**ISSN 2598-5949** | p-**ISSN 2303-1514**]

6. Conclusion and implications

This study conclusively demonstrates that PBL-based worksheets significantly enhance fifth-grade students' critical thinking skills across all measured dimensions. The experimental group showed significant improvement in providing explanations, developing basic skills, building strategies, and concluding, with substantial effect sizes (Cohen's d: 1.65-2.45) confirming the intervention's significant impact. The findings validate the effectiveness of systematically designed PBL materials in developing higher-order thinking skills among elementary students.

Theoretically, this research reinforces constructivist learning principles and extends Ennis's critical thinking framework within the context of elementary science education. It provides empirical support for the ADDIE model as a practical framework for developing targeted instructional materials. These contributions enhance our understanding of how structured problem-based approaches can systematically develop cognitive competencies in young learners within contemporary educational contexts.

Practically, the study recommends integrating PBL approaches into science education curricula and implementing teacher training programs focused on PBL methodologies. Education stakeholders should consider developing similar PBL-based materials for other subjects and grade levels. Policy makers are encouraged to incorporate critical thinking assessment into standard evaluation systems and support the widespread adoption of evidence-based teaching approaches that foster essential 21st-century skills.

7. Limitation

This study has several limitations that need to be considered, including its limited scope of implementation to a single primary school in Bandar Lampung, which requires caution when generalizing the findings. The relatively short intervention period (five learning sessions) limits the understanding of the long-term impact of PBL-based Student Worksheets on critical thinking skills. Furthermore, this study focused on Natural and Social Sciences with the topic 'Light and Its Properties,' suggesting the need for further exploration of the applicability of this approach to different learning content and contexts.

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[e-**ISSN 2598-5949** | p-**ISSN 2303-1514**]