



## DEVELOPING PROJECT-BASED SCIENCE WORKSHEETS INTEGRATING A DEEP-LEARNING PEDAGOGICAL APPROACH TO ENHANCE ELEMENTARY SCHOOL STUDENTS' CRITICAL THINKING

Nur Balqis Mutia<sup>1)</sup>, Fifi Is Juliani<sup>2)</sup>, Jelita<sup>3)</sup>, Veryawan<sup>4)</sup>,  
Anita Ekantini<sup>5)</sup>, Muhammad Singgih<sup>6)</sup>

<sup>1,2,3,4</sup> Intitut Agama Islam Negeri (IAIN) Langsa, Aceh, Indonesia

<sup>5</sup> Universitas Islam Negeri (UIN) Sunan Kalijaga, Yogyakarta, Indonesia

<sup>6</sup> Sekolah Tinggi Agama Islam (STAI) Ma'arif Kalirejo, Lampung, Indonesia

Email: [nurbalqismutia@iainlangsa.ac.id](mailto:nurbalqismutia@iainlangsa.ac.id)

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### Abstract

This study developed and evaluated a Project-Based Learning (PjBL) science worksheet integrating a deep learning pedagogical approach to support elementary students' critical thinking. Using the ADDIE research and development model, the worksheet was designed for Grade V magnetism learning at SD Negeri 4 Langsa, Aceh, Indonesia. Feasibility was assessed by six experts in media, content, and language, while practicality was evaluated through teacher and student response questionnaires. Preliminary effectiveness was examined using a one-group pretest–posttest design involving 20 students. The worksheet integrated PjBL phases with meaningful, mindful, and joyful learning principles and critical thinking indicators. Expert validation showed high feasibility for media (85.00%), content (90.14%), and language (85.00%). Student and teacher responses also indicated high practicality, with scores of 88.75% and 90.9%, respectively. Students' mean critical thinking scores increased from 43.32 (SD = 10.67) to 78.63 (SD = 14.91). The Wilcoxon signed-rank test showed a significant improvement ( $Z = -3.928$ ,  $p < .001$ ) with a large effect size ( $r = .88$ ). These findings indicate that the developed worksheet is feasible, practical, and shows preliminary potential to improve students' critical thinking. However, the absence of a comparison group limits causal interpretation.

**Keywords:** Student Worksheets, Project-Based Learning, Deep Learning Pedagogy, Critical Thinking, Elementary Science

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## INTRODUCTION

Critical thinking is widely recognized as a core 21st-century competency for solving problems, evaluating information, and making evidence-based decisions. In Indonesia, the *Kurikulum Merdeka* promotes flexible, student-centered learning and the Pancasila Student Profile, particularly its critical reasoning dimension (Ennis, 2018; Kemendikbudristek, 2022). Internationally, critical thinking is also increasingly embedded in national science curricula (Karampelas, 2023). Science learning is essential for developing this competency because it requires students to investigate natural phenomena and reason scientifically (Kelana, J. B., & Wardani, 2021; Manassero-mas et al., 2026). Critical thinking involves purposeful judgment through interpretation, analysis, evaluation, and inference (Facione, 1998, 2015), as well as reflective judgments about what to believe or do (Ennis, 2011). This study adopts five dimensions adapted from Ennis (2011) and Setyowati et al., (2022): providing simple explanations, building foundational skills, drawing conclusions, providing advanced explanations, and employing strategies and tactics.

Developing these skills requires instructional materials that guide students to question, investigate, interpret evidence, explain findings, and evaluate solutions. Project-Based Learning (PjBL) offers opportunities for authentic inquiry, collaboration, and product development, although its effectiveness depends on the quality of instructional design and support (Iswantari, 2021; Krajcik & Phyllis C. Blumenfeld, 2006). Previous studies have reported positive contributions of PjBL to elementary students' critical thinking (Afandi et al., 2024; Dongjin et al., 2024; Yudiana et al., 2024). Related research has also developed science materials integrating PjBL, STEM, and Education for Sustainable Development (Setyowati et al., 2022), examined critical thinking in physics learning (Ulpiah et al., 2024), and developed PjBL-based worksheets for elementary students (Fitriadi et al., 2023; Nadiana et al., 2023; Pramudiyanti et al., 2023). However, further research is needed to align individual PjBL stages explicitly with critical-thinking processes and translate pedagogical principles into observable worksheet features.

The need for such materials is supported by Indonesian studies reporting low critical-thinking performance among primary students (Mirna et al., 2022; Rofi'ah & Rokhmaniyah, 2024). In this study, two classroom observations and interviews with a Grade V teacher in July 2025 revealed that existing worksheets mainly contained content and questions without structured activity steps. Students were relatively passive and struggled to justify their answers, while the teacher needed more systematic instructional materials. These local findings informed the worksheet design.

To address this need, the study integrates PjBL with Indonesia's deep-learning pedagogical approach (*pembelajaran mendalam*), which emphasizes meaningful (*bermakna*), mindful (*berkesadaran*), and joyful (*menggembirakan*) learning (Feriyanto & Anjariyah, 2024; Kemendikdasmen, 2025). This approach is distinct from machine-learning techniques and the

deep and surface approaches discussed by Fullan et al., (2018). In the worksheet, meaningful learning connects magnetism to familiar objects and everyday contexts; mindful learning encourages careful observation, planning, self-monitoring, and reflection; and joyful learning incorporates hands-on experiments, drawing, collaboration, and an illustrated layout. These principles align with reported benefits for student engagement, critical thinking, creativity, and character development (Asitah et al., 2026), as well as emerging efforts to integrate deep-learning pedagogy with PjBL (Nurazizah et al., 2025).

Three research gaps therefore underpin this study: the need to clarify the alignment between PjBL stages and specific critical-thinking processes, operationalize meaningful, mindful, and joyful learning in instructional materials, and connect local needs analysis with integrated worksheet design. Accordingly, this study aimed to develop a PjBL-based Grade V science (IPAS) worksheet on magnetism integrating deep-learning pedagogy and evaluate its expert-rated feasibility, perceived practicality among students and teachers, and preliminary effectiveness in improving critical thinking through a one-group pretest–posttest pilot. The research addressed three questions: RQ1: How do media, content, and language experts rate the worksheet’s feasibility? RQ2: How practical do students and teachers perceive it to be? RQ3: Do students’ critical-thinking scores differ between the pretest and posttest after using the worksheet?.

## METHODS

This study used a Research and Development (R&D) design that followed the five stages of the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation. ADDIE was selected for its systematic structure, which allows formative evaluation at every stage so that the product can be refined before classroom use (Adeoye et al., 2024). The outputs and decision criteria of each stage are summarized in Table 1. Effectiveness was examined with a one-group pretest–posttest design during the Implementation stage; because this design has no comparison group, it provides preliminary evidence of within-group change and not evidence of a causal effect.

This study was conducted at SD Negeri 4 Langsa, Aceh, Indonesia, during the odd semester of the 2025–2026 school year. A total of 20 students were selected using total sampling, which is adequate for the small-scale formative purposes of a development study but does not support inferences at the population level. A limited trial to assess practicality involved 8 students selected based on their ability levels as assessed by the teacher, to gather feedback on readability and usability. These eight students also took part in a field trial involving all 20 students to evaluate the effectiveness of the student worksheets. The worksheets were evaluated by six experts: two media experts, two content experts, and two language experts.

The research procedure followed the five stages of ADDIE. The Analysis stage used classroom observation and interviews to identify instructional needs, learner characteristics, and alignment with the natural science learning outcomes of the Kurikulum Merdeka (Rahma et al., 2025). It consisted of two classroom observations of natural science lessons using student questionnaires and semi-structured interviews with the Grade V teacher; interviews were recorded in field notes, and the data were analyzed by domain analysis and scale analysis of Guttman-scale for questionnaires. The Design stage produced a worksheet framework that integrates the PjBL syntax with meaningful, mindful, and joyful learning features (Feriyanto & Anjariyah, 2024), with the layout prepared in Canva. The Development stage involved expert validation with Likert-scale questionnaires followed by revision. The Implementation stage consisted of the limited and field trials, with critical thinking measured by a pretest and a posttest (Susilawati et al., 2023). The Evaluation stage was formative at each stage and summative at the end of the study.

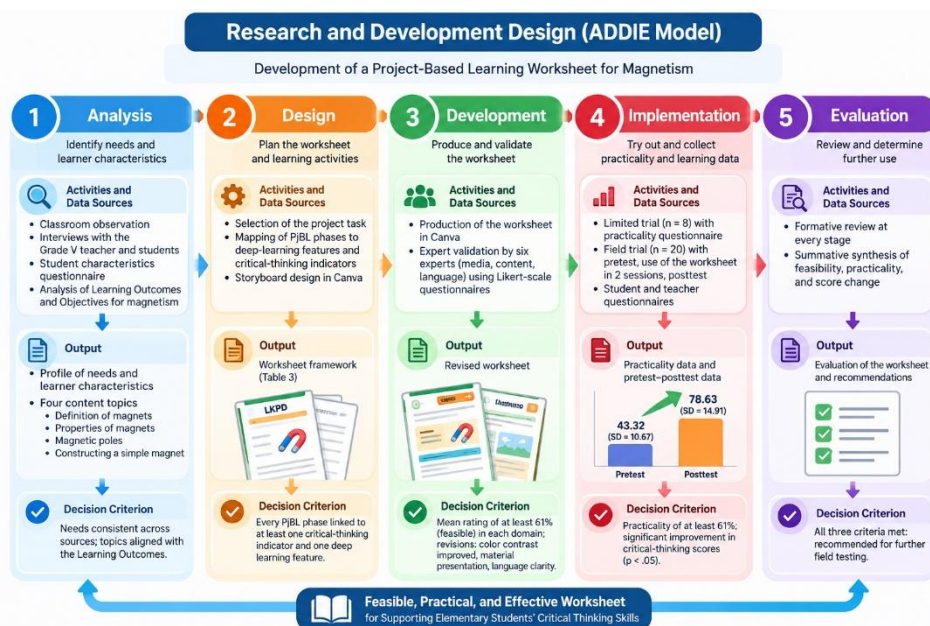


**Figure 1.** Development Flow of the Worksheet by ADDIE Stage

Data were collected with expert validation sheets, a student characteristics questionnaire, student and teacher response questionnaires, an essay-based critical-thinking test (pretest and posttest), and documentation. The test consisted of five essay items on magnetism covering the five indicators. Validity and practicality ratings were converted into percentage scores with the formula  $P = (\text{obtained score} \div \text{maximum score}) \times 100\%$  and classified using standard interpretation criteria for instructional-material development research (Rahma et al., 2025): 81% - 100% = very feasible or very practical; 61% - 80% = feasible or practical; 41% -

60% = sufficient feasible or sufficient practical; 21% - 40% = not feasible or not practical; and 0% - 20% = highly unsuitable or highly impractical. The worksheet was considered feasible and practical if it achieves a score at least 81%. Effectiveness data were analyzed through pretest–posttest comparison. The normality of the paired difference scores was examined with the Shapiro–Wilk test, and because the difference scores departed from normality, the Wilcoxon signed-rank test was used instead of a paired-samples  $t$  test (Field, 2013; Frank Wilcoxon, 2006). Results are reported as medians and interquartile ranges alongside means and standard deviations, together with the numbers of positive, negative, and tied ranks, the standardized statistic  $Z$ , the  $p$  value, and the effect size  $r = |Z| \div \sqrt{N}$  (Fritz et al., 2012), interpreted against Cohen’s conventions of .10 (small), .30 (medium), and .50 (large). The significance level was .05 (two-tailed), and analyses were run in SPSS version 22.

## RESULT AND DISCUSSION

### Preliminary Product Development Results

#### 1. Analysis Stage

##### a. Needs Analysis

Observations in two classrooms and an interview with a fifth-grade teacher showed that the worksheets used were relatively simple and lacked a structured sequence of activities, and the teacher often had to add explanations because the instructions were too general. Lessons were largely conventional rather than project-based, with relatively low student engagement. Students were highly interested in science but had not received materials that facilitate project-based learning, so the teacher requested PjBL-based worksheets integrated with deep-learning pedagogy to encourage more active, focused, and meaningful learning (Feriyanto & Anjariyah, 2024).

##### b. Student Characteristics Analysis

A questionnaire administered to all fifth-grade students profiled their interest, learning difficulties, and preferences regarding the instructional model (Table 2).

**Table 1.** Summary of Student Characteristics Questionnaire Results (n = 20)

| No | Measured Aspect                                                          | Percentage   |
|----|--------------------------------------------------------------------------|--------------|
| 1  | Students interested in natural science learning                          | 85% (17/20)  |
| 2  | Students experiencing difficulty understanding magnet material           | 70% (14/20)  |
| 3  | Students who considered the existing worksheet unclear                   | 75% (15/20)  |
| 4  | Students frequently confused while completing the worksheet              | 60% (12/20)  |
| 5  | Students interested in project-based learning                            | 95% (19/20)  |
| 6  | Students who agreed with developing a deep-learning-based PjBL worksheet | 100% (20/20) |

Most students were interested in natural science learning (17/20, 85%), yet many found the magnet material difficult (14/20, 70%) and the existing worksheet unclear (15/20, 75%); 12 of 20 (60%) were often confused when completing it, consistent with (Ngazizah et al., 2024), who reported that Grade V students commonly hold misconceptions about magnetic properties and pole interactions. Nearly all students (19/20, 95%) were interested in project-based learning, and all 20 (100%) agreed with developing the worksheet, although, as item 6 described the intended product, this unanimity may reflect acquiescence and is not evidence of readiness or effectiveness.

### **c. Curriculum Analysis Results**

SD Negeri 4 Langsa implements the Kurikulum Merdeka, so the researcher analyzed the Learning Outcomes for Grade V (Phase C) natural and social sciences (Badan Standar, Kurikulum, 2025) in decree No. 046/H/KR/2025 and the school's Learning Objectives flow for the magnet topic, which covers basic concepts, magnetic properties, applications in daily life, and constructing a simple magnet. Its progression was intended to cultivate critical thinking and creativity through project activities carrying the meaningful, mindful, and joyful features (Feriyanto & Anjariyah, 2024).

### **d. Material Determination**

The worksheet material therefore comprised four topics: the definition of magnets, magnetic properties, magnetic poles, and the procedure for constructing a simple magnet, integrated with the PjBL syntax so that students observe phenomena, analyze experimental data, and construct concepts independently and collaboratively, consistent with the emphasis of project-based learning on authentic experiences for strengthening critical thinking (Iswantari, 2021).

## **2. Design Stage**

The design framework drew on the needs, student characteristics, and curriculum analyses. The worksheet comprises its identity, Learning Outcomes and Objectives, instructions for use, a brief content summary, six PjBL phases (essential question, project planning, activity schedule, monitoring of project progress, assessment of results, and evaluation and learning development), a conclusion, and a reflection. As Table 3 shows, each component scaffolds a specific critical-thinking process, from trigger questions that prompt students to justify their thinking to observation tables, analysis questions, and reflection prompts that require recording evidence, explaining, inferring, and evaluating.

**Table 2.** Design Framework Mapping PjBL Phases to Deep-Learning Features, Worksheet Activities, and Critical-Thinking Indicators

| PjBL Phase                                    | Key Worksheet Activity                                                                                              | Deep-Learning Feature                                                                                                           | Critical-Thinking Indicator                                       |
|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| <b>1. Essential Question</b>                  | Read a short contextual text on magnets and discuss three trigger questions in groups.                              | <b>Meaningful:</b> connects magnet concepts with everyday objects. <b>Joyful:</b> uses illustrations and discussion.            | Providing simple explanations                                     |
| <b>2. Planning the Project</b>                | Identify tools and materials and follow procedures for investigating magnets and their characteristics.             | <b>Mindful:</b> plans procedures before action. <b>Meaningful:</b> uses familiar, accessible materials. <b>Mindful:</b> manages | Providing strategies and tactics                                  |
| <b>3. Scheduling Activities</b>               | Develop a project schedule, assign responsibilities, and organize group tasks.                                      | time and responsibility. <b>Joyful:</b> promotes collaboration. <b>Mindful:</b> encourages                                      | Providing strategies and tactics                                  |
| <b>4. Monitoring Project Progress</b>         | Conduct magnet experiments, record observations, and illustrate iron-filing patterns.                               | careful observation. <b>Joyful:</b> emphasizes hands-on investigation.                                                          | Building foundational skills                                      |
| <b>5. Assessing Results</b>                   | Analyze experimental findings through questions about magnetic attraction, pole interaction, and observed patterns. | <b>Meaningful:</b> explains observed scientific phenomena.                                                                      | Providing advanced explanations                                   |
| <b>5a. Conclusion and Presentation</b>        | Formulate group conclusions and present findings to the class.                                                      | <b>Mindful:</b> consolidates learning. <b>Joyful:</b> shares learning outcomes. <b>Mindful:</b> reflects on learning.           | Summarizing                                                       |
| <b>6. Evaluation and Learning Development</b> | Reflect on new learning, the value of direct experimentation, and ideas for future magnet projects.                 | <b>Meaningful:</b> connects learning with future applications.                                                                  | Providing strategies and tactics; providing advanced explanations |

The project task, investigating magnetic properties with bar magnets and iron filings and constructing a simple magnet, was chosen from three candidates for age appropriateness, low-cost materials, conceptual demand, safety, and potential to elicit critical thinking, and the Canva design was compiled into a storyboard.

### 3. Development Stage

#### a. Worksheet Media Development

The worksheet was produced in Canva (A4) by the researcher; Pinterest was used only for layout ideas, and all illustrations were Canva licensed elements, with no images copied from Pinterest.

The worksheet contains a cover page, preface, table of contents, Learning Outcomes, Learning Objectives, instructions for use, the six PjBL phases with magnet material, trigger questions, and observation activities, and a reference list, author biography, and back cover, with clearly separated phase headings, short illustrated texts, and writing spaces for answers.

**1 Essential Question**

A short reading on magnets and their properties with everyday examples, followed by three trigger questions for group discussion.

- ✓ Short reading on magnets
- ✓ Everyday examples
- ✓ Three discussion questions

**Phase 1 Essential Question**

**Magnet in Everyday Life**

Magnets can be found in many objects around us, such as door locks, speakers, and refrigerator doors. Magnets can attract various materials, such as iron, nickel, and cobalt. They have two poles, north and south, and can attract or repel each other.

Refrigerator door Speaker Compass

**Discussion Questions**

1. Where do we find magnets in everyday life?
2. What objects can be attracted by a magnet?
3. How do magnets make our lives easier?

Write your ideas here:

**2 Planning the Project**

Lists of tools and materials and step-by-step procedures for the first investigations, "What is a magnet?" and magnet characteristics.

- ✓ Tools and materials
- ✓ Step-by-step procedures
- ✓ Two initial investigations

**Phase 2 Planning the Project**

**Tools and Materials**

Magnet Paper clips Nails Plastic ruler

**Investigation 1 What is a Magnet?**

**Steps:**

1. Prepare the tools and materials.
2. Bring the magnet close to various objects.
3. Observe which objects are attracted to the magnet.
4. Record your findings.

**3-4 Project Implementation**

The project schedule and task-allocation table, and the observation table with the hint to observe carefully and thoroughly.

- ✓ Project schedule
- ✓ Task-allocation table
- ✓ Observation table

**Phases 3 and 4 Project Schedule and Task Allocation**

**Project Schedule**

| Week | Activities                            |
|------|---------------------------------------|
| 1    | Planning and preparation              |
| 2    | Investigation and data collection     |
| 3    | Data analysis and product development |
| 4    | Finalization and presentation         |

**Task Allocation**

| Group Member | Task/Responsibility |
|--------------|---------------------|
|              |                     |
|              |                     |
|              |                     |

**Observation Table**

| Object Tested | Attracted (Yes/No) | Notes / Observations |
|---------------|--------------------|----------------------|
|               |                    |                      |
|               |                    |                      |
|               |                    |                      |
|               |                    |                      |

Observe carefully and thoroughly.

**5-6 Conclusion and Evaluation**

The conclusion page, where groups write conclusions and prepare to present them, and Phase 6 (Evaluation and Learning Development) with three reflection prompts.

- ✓ Group conclusion
- ✓ Preparation for presentation
- ✓ Three reflection prompts

**Phase 5 Conclusion**

Write your group's conclusion based on the investigations results.

Prepare to present your conclusion to the class.

**Phase 6 Evaluation and Learning Development**

1. What new thing did you learn from this project?
2. What challenges did your group face? How did you solve them?
3. How can you use what you learned in real life?

**Figure 2.** Representative Pages of the PjBL Natural Science Worksheet with the Deep-Learning Pedagogical Approach

#### b. Product Feasibility Validation

The feasibility of the worksheet was rated by six experts. Their ratings are combined in Table 5.

**Table 3.** Combined Recapitulation of Media, Content, and Language Expert Rating Results

| No | Validator | Aspect Assessed                       | Score (%)    | Criterion            |
|----|-----------|---------------------------------------|--------------|----------------------|
| 1  | Media     | Media Quality                         | 81.25        | Very Feasible        |
| 2  | Media     | Visual                                | 75.00        | Feasible             |
| 3  | Media     | Media Suitability                     | 96.00        | Very Feasible        |
|    |           | <b>Media Expert Mean</b>              | <b>85.00</b> | <b>Very Feasible</b> |
| 4  | Content   | Material Alignment                    | 83.33        | Very Feasible        |
| 5  | Content   | Material Presentation                 | 82.50        | Very Feasible        |
| 6  | Content   | Usefulness                            | 87.50        | Very Feasible        |
| 7  | Content   | Project Based Learning Characteristic | 96.87        | Very Feasible        |
| 8  | Content   | Deep Learning Integration             | 91.67        | Very Feasible        |
|    |           | <b>Content Expert Mean</b>            | <b>90.14</b> | <b>Very Feasible</b> |
| 9  | Language  | Language Suitability                  | 82.50        | Very Feasible        |
| 10 | Language  | Language Readability                  | 87.50        | Very Feasible        |
|    |           | <b>Language Expert Mean</b>           | <b>85.00</b> | <b>Very Feasible</b> |

*Source: Processed data (2026)*

As shown in Table 5, 9 of the 10 aspects rated fell in the very feasible category (81–100%) and one, the visual aspect of the media rating (75.00%), in the feasible category (61–80%). The highest ratings were for PjBL characteristics (96.87%), media suitability (96.00%), and deep-learning integration (91.67%), indicating that both frameworks were perceived as reflected in the worksheet; whether the integration worked as intended during lessons was not observed.

The lowest rating was for the visual aspect (75.00%), because the initial color scheme had insufficient contrast; the colors were revised. Media quality (81.25%), material presentation (82.50%), material alignment (83.33%), and language suitability (82.50%) were also lower, though still very feasible. The unweighted mean of the three domain means was 86.71% (very feasible), a summary only because the domains differ in numbers of aspects and items. The experts' notes were used to revise the product before the student trials.

#### 4. Implementation Stage

##### a. Student Practicality Test

Student practicality was evaluated with a 10-item questionnaire on a 4-point scale. In the limited pilot ( $n = 8$ ), the average score was 3.55, equivalent to 88.75% (very practical); six students rated the product “very practical” and two “practical,” with individual scores from 77.50% to 100% and a standard deviation of 0.32.

##### b. Teacher Response to the Worksheet

Two teachers also evaluated the worksheet, giving an overall average score of 3.64, or 90.9% (very practical). Language scored highest (93.8%), followed by content (91.7%), PjBL and deep learning (90.6%), and media and presentation (87.5%); with only two respondents, this is formative feedback and not a basis for broad claims.

Teachers considered the worksheet easy to use, visually appealing, clearly formulated, and appropriate for fifth-grade students (perceptions, not observations of actual use), with a systematic activity structure and relevant content. They noted that visual presentation and the clarity of instructions in some stages could be improved, and this feedback will be used to refine the worksheet.

### c. Effectiveness of the Worksheet in Enhancing Critical Thinking by Indicator

The critical-thinking test had a maximum total score of 15, with a maximum of 2, 3, or 4 per indicator. As shown in Table 6, all 20 students scored higher on the posttest (20 positive ranks, no negative ranks, no ties), a statistically significant difference ( $Z = -3.928$ ,  $p < .001$ ) with a large effect ( $r = .88$ ). Without a comparison group, this indicates within-group improvement and cannot separate the worksheet's effect from testing effects, maturation, teacher influence, or other concurrent factors.

**Table 4.** Pretest–Posttest Critical Thinking Scores and Wilcoxon Signed-Rank Test Results  
( $N = 20$ )

| Measure                   | Pretest       | Posttest      |
|---------------------------|---------------|---------------|
| Mean (SD)                 | 43.32 (10.67) | 78.63 (14.91) |
| Median (IQR)              | 40.00 (6.60)  | 83.30 (13.30) |
| Mean indicator score      | 1.29          | 2.35          |
| Wilcoxon Signed-Rank Test | Result        |               |
| Positive ranks            | 20            |               |
| Negative ranks            | 0             |               |
| Ties                      | 0             |               |
| Z                         | -3.928        |               |
| $p$ (two-tailed)          | < .001        |               |
| Effect size, $r$          | .88           |               |

Pretest and posttest mean scores for each of the five critical-thinking indicators are shown in Table 7.

**Table 5.** Pretest and Posttest Critical-Thinking Scores by Indicator

| Critical Thinking Indicator      | Pretest Mean | Posttest Mean | Improvement |
|----------------------------------|--------------|---------------|-------------|
| Providing Simple Explanations    | 1.65         | 1.95          | 0.30        |
| Building Foundational Skills     | 1.10         | 1.85          | 0.75        |
| Summarizing                      | 1.15         | 2.40          | 1.25        |
| Providing Advanced Explanations  | 1.30         | 2.85          | 1.55        |
| Providing Strategies and Tactics | 1.25         | 2.70          | 1.45        |
| <b>Average</b>                   | <b>1.29</b>  | <b>2.35</b>   | <b>1.06</b> |

Source: Processed data (2026)

Table 7 shows higher posttest than pretest means on all five indicators (mean indicator score from 1.29 to 2.35), with the largest increases for providing advanced explanations (1.55 points) and providing strategies and tactics (1.45) and the smallest for providing simple explanations (0.30 points, from 1.65 to 1.95).

These indicator-level differences are descriptive: larger gains may reflect worksheet activities requiring explanation and planning, but also baseline differences (simple explanations started highest), floor or ceiling effects, or unequal item difficulty. Because indicator-specific inferential tests were not conducted, the findings do not show that every indicator improved significantly.

## 5. Evaluation Stage

Evaluation drew on expert ratings, student and teacher responses, and pretest–posttest results. The worksheet was rated very feasible by the six experts and very practical by students and teachers, and was followed by a significant within-group improvement in critical-thinking scores. These results meet the criteria set for this development study and indicate that the worksheet is promising for further field testing as supplementary material in Grade V natural science lessons, but do not establish its effectiveness beyond this pilot sample.

## DISCUSSION

The experts rated all three domains as very feasible (85.00–90.14%), with the lowest rating for visual design, where insufficient color contrast was corrected. Such ratings are not psychometric validity evidence, and with only two experts per domain they say nothing about inter-expert agreement. Practicality ratings from students and teachers were also very practical, but as perception data from small samples they show acceptability, not demonstrated usability in observed classroom use.

Critical-thinking scores increased for all 20 students, with a large within-group effect ( $r = .88$ ). A plausible explanation lies in the worksheet design: each phase asks students to do something that matches a critical-thinking indicator (Table 3), such as stating what they think, planning procedures, recording careful observations, explaining why iron-filing patterns form, drawing conclusions, and evaluating what they learned. This scaffolded practice is consistent with meta-analytic evidence that critical-thinking gains are larger when students work on authentic problems and engage in dialogue (Abrami et al., 2015) and with reports that PjBL and PjBL-based worksheets are associated with better critical thinking (Afandi et al., 2024; Dongjin et al., 2024; Yudiana et al., 2024). Observing pole interactions may also address the misconceptions about magnetic properties reported for Grade V students (Ngazizah et al., 2024), although conceptual understanding was not measured. These remain hypotheses, since practice effects, maturation, the teacher's own instruction, and the novelty of a new format are

rival explanations (Shadish et al., 2002); the result therefore indicates promising within-group improvement, not that the worksheet caused it, and the study cannot show whether the deep-learning integration added value beyond PjBL alone.

This was a single-school study with 20 students selected with the teacher's input, no comparison group, and a short intervention of two lessons, and some students may have used the worksheet in both trials. Practicality data are self-reported, and indicator-level changes were not tested inferentially. Future studies should use several schools and a comparison group, delayed posttests, content-validity indices and inter-rater reliability, and indicator-level analyses with correction for multiple comparisons.

## CONCLUSION

This study developed a PjBL natural science worksheet that integrates the deep-learning pedagogy for Grade V magnetism and evaluated it in a pilot at SD Negeri 4 Langsa. Six experts rated the worksheet as very feasible in media, content, and language, and students and teachers perceived it as very practical. Students' critical-thinking scores improved significantly from pretest to posttest in this pilot sample (Wilcoxon  $Z = -3.928$ ,  $p < .001$ ,  $r = .88$ ); because the design had no comparison group, the findings indicate promising within-group improvement and do not establish that the worksheet alone caused it. The study also contributes a design framework that links PjBL phases, deep-learning features, worksheet activities, and critical-thinking indicators and that can be adapted to other topics.

These findings should be read in light of their limitations: a single school, 20 students, a one-group design, possible repeated exposure between trial stages, and self-reported practicality data. Within these limits, teachers in contexts similar to the pilot setting may try the worksheet as supplementary material for teaching magnetism, and broader adoption should follow multi-school validation and comparative testing. Future researchers could adapt the worksheet to other topics or educational levels, test it against a comparison condition, and develop an interactive digital version to suit digital-native learners.

## AUTHOR CONTRIBUTION

NBM: conceptualization, methodology, and writing original draft, writing review and editing. FIJ: worksheet development, investigation, formal analysis, and editing. J: data curation, visualization, supervision, validation, and resources. V: supervision, validation AN: supervision, validation MS: supervision, validation. All authors have read and approved the final version of the manuscript. All the writers, agreed to the final version of the paper and say there are no problems, with the way this study is being shared.

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