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Effects of Crocodile Chemistry Lab–Assisted Problem-Based Learning on Students' Problem-Solving Ability and Scientific Attitude in Thermochemistry

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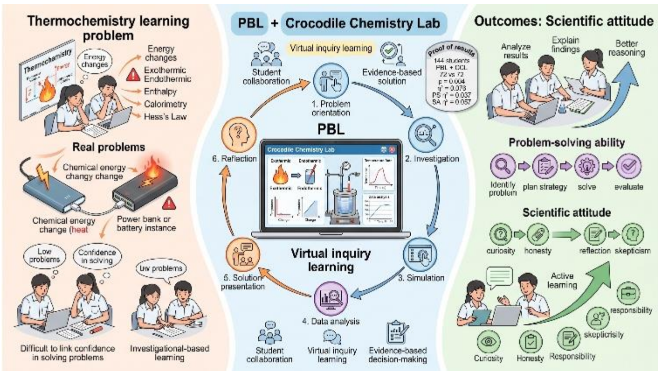
ABSTRACT



Developing students' problem-solving ability and scientific attitude remains a challenge in chemistry education, particularly in thermochemistry, which requires conceptual reasoning and scientific inquiry. Although Problem-Based Learning (PBL) and virtual laboratory simulations have demonstrated potential benefits, their integration to support both cognitive and affective outcomes requires further investigation. This study examined the effect of Crocodile Chemistry Lab–assisted PBL on students' problem-solving ability and scientific attitude in thermochemistry learning. A quasi-experimental pretest–posttest control group design was conducted involving 144 eleventh-grade science students at a public senior high school in Pekalongan Regency, Indonesia, during the 2025/2026 academic year. The experimental group received PBL instruction assisted by Crocodile Chemistry Lab simulations, while the control group was taught using the scientific approach (5M). Data were collected using an essay-based problem-solving test and a Likert-scale scientific attitude questionnaire validated through expert judgment and Rasch model analysis. Data were analyzed using descriptive statistics and multivariate analysis of variance (MANOVA). The results showed a significant difference between groups, with the experimental group achieving higher scores in both outcomes. However, the effect sizes were small, with partial eta squared values of 0.037 for problem-solving ability, 0.057 for scientific attitude, and 0.076 for the overall effect. These findings indicate that Crocodile Chemistry Lab–assisted PBL provides a statistically significant but modest contribution to supporting cognitive and affective outcomes in chemistry learning.

Keywords: *crocodile chemistry lab; problem-based learning; problem-solving skills; scientific attitude; thermochemistry*

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INTRODUCTION

Technological advancements in the era of the Industrial Revolution 4.0 and Society 5.0 have brought significant changes to the field of education [1]. Students are expected not only to master factual knowledge but also to possess high-level thinking skills such as critical, creative, and collaborative thinking, as well as problem-solving abilities that are adaptable to the dynamics of the times [2],[3]. National education regulations through Government Regulation No. 4 of 2022 emphasize that education graduates must possess critical thinking and problem-solving skills, therefore, learning in schools needs to be designed to strengthen these competencies from an early age [4]-[7] . However, the PISA 2022 results show that Indonesian students' science literacy is still low (average score 383), indicating weak analytical and problem-solving skills among students [8]. This condition poses a serious challenge to efforts to improve the quality of education.

Problem-solving ability is a crucial cognitive skill because it involves the processes of identifying problems, analyzing alternatives, and making decisions based on logical evidence [9],[10]. Unfortunately, research shows that these skills are still weak in Indonesian students, which impacts their low learning outcomes. On the other hand, scientific attitude factors are equally important. Attitudes such as curiosity, openness to data, objectivity, and critical thinking support the development of better problem-solving skills [11], [12]. However, research by Wildayanto & N, (2020) indicates that the scientific attitudes of high school students in Indonesia remain relatively low, thereby limiting their ability to engage in critical and evidence-based learning.

These limitations are exacerbated by teaching practices that are still dominated by a teacher-centered approach. Methods that only emphasize concept transfer without allowing for exploration tend to make students passive. As a result, they struggle to connect theory with real-world phenomena and lack practice in analytical thinking. In fact, in chemistry a subject full of abstract concepts a strategy is needed that provides students with the opportunity to construct their own understanding through contextual and investigative learning experiences [14]-[16].

One model believed to address this issue is Problem-Based Learning (PBL). PBL encourages students to solve contextual problems through investigation, discussion, and collaboration [17]. This approach aligns with the needs of 21st-century learning because it provides students with opportunities to think critically and creatively, as well as to practice scientific attitudes [18]-[20]. However, despite its potential, the implementation of Problem-Based Learning (PBL) in secondary school chemistry remains limited [21], [22]. Previous studies have demonstrated that PBL can enhance students' higher-order thinking skills and engagement, while other studies have highlighted the benefits of virtual laboratories in improving conceptual understanding and providing flexible learning environments. Nevertheless, these lines of research are often conducted separately, with limited attention to the integration of PBL and simulation-based tools in a unified instructional approach.

One relevant medium is the Crocodile Chemistry Lab, a virtual laboratory simulation software that allows students to perform experiments interactively. Through this simulation, students can manipulate variables, observe reaction results, and draw conclusions just as they would in a real experiment [23]. The advantages of this medium are its ability to provide a safer, more practical, and flexible laboratory experience, while simultaneously increasing students' motivation, problem-solving skills, and scientific attitude. Integrating PBL with Crocodile Chemistry Lab has the potential to provide a richer learning experience by combining problem-based learning with virtual experimental exploration.

Although numerous studies in the last five years have reported that Problem-Based Learning (PBL) effectively enhances higher-order thinking skills and scientific attitudes [18], [20] and other studies have highlighted the role of virtual laboratory simulations in improving conceptual understanding and student engagement [24],[25], these approaches are predominantly implemented in isolation, with limited integration in secondary-level chemistry education [26], [27]. Moreover, previous research tends to focus predominantly on cognitive outcomes, while relatively few studies simultaneously examine both cognitive and affective domains such as scientific attitudes within the same intervention [28],[29].

The urgency of this research becomes even clearer when considering the context of thermochemistry material. This topic is known to be challenging because it demands an understanding of energy concepts, the laws of thermodynamics, and complex enthalpy calculations [25]. Based on a preliminary interview with a chemistry teacher at a public senior high school in Pekalongan Regency conducted on February 19, 2025, only about 26% of eleventh-grade students achieved the Minimum Completion Criteria (KKM) in thermochemistry. Many students have difficulty connecting theory with real-world phenomena and demonstrate weak scientific attitudes in evaluating experimental data. This fact reinforces the need for learning innovations that not only enhance conceptual understanding but also develop problem-solving skills and scientific attitudes [29], [30].

The present study addresses this gap by integrating Crocodile Chemistry Lab with Problem-Based Learning (PBL) as a simulation-assisted approach for thermochemistry learning. Previous studies have generally examined PBL and virtual laboratory simulations separately, with greater emphasis on cognitive outcomes, while limited attention has been given to their integration in supporting both cognitive and affective domains. This study provides empirical evidence on the implementation of technology-supported PBL by simultaneously examining students' problem-solving ability and scientific attitude. Therefore, this study aims to analyze the effect of Crocodile Chemistry Lab–assisted Problem-Based Learning (PBL) on students' problem-solving ability and scientific attitude in thermochemistry learning. Specifically, this study compares the learning outcomes of students receiving simulation-assisted PBL instruction with those receiving instruction using the scientific approach and estimates the magnitude of the effects on both outcomes.

METHODS

1. Research Design

This study employed a quasi-experimental design using a pretest–posttest control group format. Two groups were involved: an experimental group (N = 72) and a control group (N = 72). The experimental group received instruction through Problem-Based Learning (PBL) assisted by Crocodile Chemistry Lab, while the control group was taught using the scientific approach (5M). The main differences between learning activities in the experimental and control classes are presented in Table 1.

Table 1. Comparison of learning activities in experimental and control classes

Class Experiment (PBL + Crocodile Chemistry Lab)	Control Class (5M Scientific Approach)
(1) Problem Orientation: The teacher presents a real-life case report of a power bank explosion on an airplane. Students observe and analyze the incident to identify issues related to energy changes in chemical reactions.	**(1) Observing:** The teacher opens the lesson by showing images/videos of exothermic and endothermic reactions. Students observe the phenomena and record important points.
(2) Organizing Students: Students work in groups to formulate investigative questions and hypotheses based on the case analysis. The teacher forms groups and explains learning objectives based on identified problems.	**(2) Questioning:** Students formulate questions based on their observations. The teacher guides them in identifying learning problems and objectives.
(3) Guiding Investigation: Students explore exothermic and endothermic reactions using Crocodile Chemistry Lab, collect temperature data, and observe energy changes.	**(3) Experimenting/Collecting Information:** Students look for information from textbooks/LKS to collect data about temperature changes in reactions.
(4) Developing and Presenting Results: Students analyze simulation results, connect them to thermochemical theory, and compare them with the actual event.	**(4) Associating:** Students discuss the results of observations to understand exothermic and endothermic concepts.
(4) Developing and Presenting Results: Students compile group reports and present scientific solutions to prevent similar incidents. The teacher supports students in strengthening argumentation using data. **(5) Evaluation and Reflection:** Students reflect on the learning process and relate thermochemistry concepts to battery and power bank technologies.	**(5) Communicating:** Students draw conclusions, present the results of class discussions regarding energy changes in chemical reactions, and reflect on the learning activities, while the teacher provides final reinforcement and evaluation.

2. Participants

This study was conducted at a public senior high school in Pekalongan Regency, Indonesia, during the 2025/2026 academic year. The accessible population consisted of eleventh-grade students enrolled at the selected school. The school was selected purposively based on curriculum alignment, school accreditation, and accessibility for research implementation.

Four intact classes were selected as research samples using cluster random sampling. Two classes (XI F1 and XI F5) were assigned as the experimental group, while two classes (XI F2 and XI F6) were assigned as the control group. The total number of participants was 144 students, with 36 students in each class.

Students' previous chemistry achievement scores from the most recent semester examination were analyzed using an independent samples t-test to examine baseline equivalence between groups. The result showed no significant difference between the experimental and control groups ($p > 0.05$), indicating comparable initial academic characteristics before the intervention. Table 2 presents the distribution of participants across the experimental and control classes.

Table 2. Number of students and class distribution

No	Class	Information	Number of Students
1	XI F1	Experiment	36
2	XI F5	Experiment	36
3	XI F2	Control	36
4	XI F6	Control	36

3. Instruments

The research instruments consisted of a problem-solving ability test and a scientific attitude questionnaire. The problem-solving ability instrument was developed as an essay-based test to evaluate students' ability in solving thermochemistry problems. The initial instrument consisted of 15 items developed based on four indicators: problem understanding, strategy planning, solution implementation, and evaluation. The test covered thermochemistry concepts, including enthalpy changes, Hess's law, calorimetry, and bond energy. Empirical validation using the Rasch model resulted in the exclusion of four items (items 6, 8, 12, and 14) that did not meet the item fit criteria. Therefore, 11 valid items were retained for the final assessment. The blueprint of the problem-solving ability test is presented in Table 3.

Table 3. Blueprint of problem-solving ability test

Indicator	Description	Level	Items
Problem Understanding	Identifying and interpreting thermochemistry problems	C3–C4	3
Strategy Planning	Designing solution strategies	C4–C5	3
Solution Implementation	Applying formulas and calculations	C3–C5	3
Evaluation	Reflecting and evaluating solutions	C5–C6	2
Total			**11**

Students' scientific attitudes were measured using a Likert-scale questionnaire. The questionnaire was initially composed of 25 items representing five indicators: curiosity, academic honesty, reflective thinking, scientific skepticism, and responsibility. Based on empirical validation results, three items (items 4, 8, and 13) were removed because they did not satisfy the validation criteria. The final questionnaire consisted of 22 valid items. The distribution of items and descriptions of each scientific attitude indicator are presented in Table 4.

Table 4. Scientific attitude instrument blueprint

Indicator	Number of Items	Description
Curiosity	5	Interest in exploring scientific phenomena
Academic Honesty	5	Reporting data truthfully
Reflective Thinking	4	Evaluating one's own understanding
Scientific Skepticism	4	Evaluating evidence critically
Responsibility	4	Completing tasks responsibly
Total	**22**	

The validity and reliability of both instruments were examined through theoretical and empirical approaches. Content validity was established through expert judgment involving five experts in chemistry education and two experts in instructional media. The Aiken's V index for both instruments was 0.97, indicating high content validity. Empirical validation was further conducted using the Rasch model with Winsteps software. Item fit was evaluated based on Outfit Mean Square (MNSQ), Outfit Z-standard (ZSTD), and Point-Measure Correlation criteria, and items that did not meet the criteria were excluded from the final instruments. Reliability analysis showed that the problem-solving ability test obtained a Cronbach's alpha value of 0.76, while the scientific attitude questionnaire obtained a value of 0.78, indicating that both instruments had acceptable internal consistency and were suitable for use in this study.

4. Data Collection Procedure

Data collection was conducted through four stages: pretest, treatment, posttest, and supporting data collection. The pretest was administered to both the experimental and control groups one week before the intervention to measure students' initial problem-solving ability and scientific attitude and to determine the baseline condition of both groups before treatment.

The treatment was conducted during three meetings in the thermochemistry learning unit. The experimental group was taught using Problem-Based Learning (PBL) assisted by Crocodile Chemistry Lab simulations, whereas the control group received instruction using the scientific approach (5M). PBL emphasizes learning through authentic problems, investigation, and the development of students' problem-solving skills, while simulation-based learning can support visualization of abstract chemistry concepts [citation]. Both groups were taught by the same teacher to maintain consistency in instructional implementation.

The posttest was administered after the completion of the intervention to evaluate changes in students' problem-solving ability and scientific attitude. The obtained results were used to determine the effectiveness of the instructional approach. Additional supporting data were collected through classroom observations and students' group reports to provide contextual information and support the interpretation of quantitative findings.

5. Data Analysis

The collected data were analyzed using Multivariate Analysis of Variance (MANOVA) with the assistance of SPSS version 25. Before conducting MANOVA, prerequisite tests were performed, including normality testing, homogeneity of covariance matrices using Box's M test, and multicollinearity analysis [31]. These steps are in line with standard practice in recent educational research [32], which emphasize that valid MANOVA results rely on fulfilling these prerequisites.

The MANOVA analysis was conducted to evaluate the overall effect of Problem-Based Learning assisted by Crocodile Chemistry Lab simulations on students' problem-solving ability and scientific attitude simultaneously. Hotelling's Trace was used to interpret the multivariate effect, followed by univariate ANOVA to determine the contribution of each dependent variable when a significant MANOVA result was obtained. The treatment effect was assessed using eta squared (η^2), with values of 0.01, 0.06, and 0.14 representing small, medium, and large effects, respectively. Pillai's Trace was applied as an alternative multivariate statistic when the Box's M test indicated a violation of covariance homogeneity assumptions.

RESULTS AND DISCUSSION

1. Data Characteristics and Preliminary Analysis

The prerequisite analyses were conducted before performing the MANOVA to ensure that the data met the assumptions required for multivariate analysis. The assumption testing included multivariate outlier analysis, normality, linearity, homogeneity of covariance matrices, and multicollinearity between dependent variables.

The Mahalanobis distance analysis indicated that all cases were below the critical chi-square value of $\chi^2(2) = 13.82$ at $p < 0.001$, suggesting that no multivariate outliers were detected. The Kolmogorov–Smirnov test showed that the data distribution met the normality assumption ($p > 0.05$). The linear relationship between problem-solving ability and scientific attitude was confirmed through linearity analysis, while the correlation coefficient between the two dependent variables was $r = 0.407$. This value indicated a moderate relationship and confirmed that multicollinearity was not present because the correlation remained below the recommended threshold.

The Box's M test showed homogeneous covariance matrices between groups (Box's M = 2.093; F = 0.687; p = 0.560). These findings indicated that the data satisfied the assumptions required for MANOVA analysis [31]. The descriptive statistics of students' problem-solving ability and scientific attitude are presented in Table 5 and Table 6.

The descriptive results show that both groups experienced improvements after the learning intervention. The experimental group obtained higher posttest scores in both problem-solving ability and scientific attitude compared with the control group. These differences were further examined through multivariate and univariate analyses.

Table 5. Descriptive statistics of problem-solving ability

Group	N	Mean Pretest	Mean Posttest
Experimental	72	42,93	62,80
Control	72	45,82	55,83

Table 6. Descriptive statistics of scientific attitude

Group	N	Mean Pretest	Mean Posttest
Experimental	72	61,33	75,08
Control	72	59,31	68,38

2. Overall Effect of Crocodile Chemistry Lab-Assisted PBL on Learning Outcomes

MANOVA was conducted to examine whether the implementation of Problem-Based Learning (PBL) assisted by Crocodile Chemistry Lab resulted in differences in students' problem-solving ability and scientific attitude simultaneously. The multivariate test results are presented in Table 7.

Table 7. Results of multivariate test

No	Types of Multivariate Analysis	*Sig.*	*Partial Eta Squared*
1	*Pillai's Trace*	0.004	0.076
2	*Wilks' Lambda*	0.004	0.076
3	*Hotelling's Trace*	0.004	0.076
4	*Roy's Largest Root*	0.004	0.076

The MANOVA results indicated a statistically significant difference between the experimental and control groups ($p = 0.004 < 0.05$). The partial eta squared value ($\eta^2 p = 0.076$) indicated a modest overall effect of the instructional approach on the combined learning outcomes. This finding suggests that Crocodile Chemistry Lab-assisted PBL contributed to differences in students' cognitive and affective outcomes, although the magnitude of the effect remained limited.

The limited effect size may be associated with the relatively short intervention period and the complexity of developing problem-solving ability and scientific attitude. These outcomes generally require sustained learning experiences involving repeated inquiry, reflection, and scientific practice. Previous studies have shown that PBL can support higher-order thinking development because students engage in problem identification, investigation, discussion, and evaluation processes [18], [19], [21]. The current findings extend previous evidence by demonstrating that the integration of PBL with a virtual laboratory environment can provide additional support for chemistry learning. The follow-up univariate analysis was conducted to determine the contribution of each dependent variable. The results are presented in Table 8.

Table 8. Univariate test results

Dependent Variable		Mean Square	F	Sig.	Partial Eta Squared
Problem-Solving Ability	Contrast	1743,063	5,38	.022	.037
	Error	323,957			
Scientific Attitude	Contrast	1613,361	8,53	.004	.057
	Error	188,962			

The analysis showed significant differences between groups in problem-solving ability ($p = 0.022$; $\eta^2 p = 0.037$) and scientific attitude ($p = 0.004$; $\eta^2 p = 0.057$). The effect size values indicate that the intervention produced statistically significant but small effects. The findings suggest that Crocodile Chemistry Lab-assisted PBL has potential as a supporting instructional strategy, while learning duration and other contextual factors may influence the magnitude of the outcomes.

3. Effect of Crocodile Chemistry Lab-Assisted PBL on Students' Problem-Solving Ability

The univariate analysis presented in Table 8 revealed a significant difference in students' problem-solving ability between the experimental and control groups ($F = 5.381$, $p = 0.022$, $\eta^2p = 0.037$). The experimental group achieved a higher posttest mean score ($M = 62.80$) compared with the control group ($M = 55.83$), indicating that students who received Crocodile Chemistry Lab-assisted Problem-Based Learning (PBL) demonstrated better problem-solving performance after the intervention. The effect size indicated a small effect, suggesting that the intervention provided a positive contribution but with a limited practical magnitude. This finding indicates that the improvement in problem-solving ability was influenced not only by the instructional approach but also by other contextual factors, such as students' prior knowledge, learning experience, and familiarity with simulation-based learning.

The difference between groups may be associated with the characteristics of PBL, which emphasizes authentic problems, collaborative investigation, and reflective evaluation. The learning process required students to analyze contextual situations, formulate hypotheses, collect evidence, and construct solutions based on scientific reasoning. These activities encouraged students to move beyond procedural understanding and apply thermochemical concepts in meaningful problem-solving situations. Previous studies have shown that PBL supports students' problem-solving ability by providing opportunities to investigate contextual problems and develop solutions collaboratively [18], [21]. The findings strengthen previous evidence that problem-based learning can facilitate higher-order cognitive processes in chemistry education.

The integration of Crocodile Chemistry Lab further supported the problem-solving process by providing opportunities for students to explore thermochemical phenomena through simulation-based experiments. Students were able to observe temperature changes, manipulate variables, and connect experimental evidence with theoretical concepts that are difficult to visualize through conventional instruction. Virtual laboratory environments can provide interactive learning experiences that allow students to explore scientific phenomena while maintaining connections between observation and conceptual understanding [23], [26]. The combination of PBL and virtual experimentation created a learning environment where students could test ideas, interpret evidence, and refine their explanations during the problem-solving process. The distribution of students' problem-solving ability categories in the experimental group is presented in Figure 1.

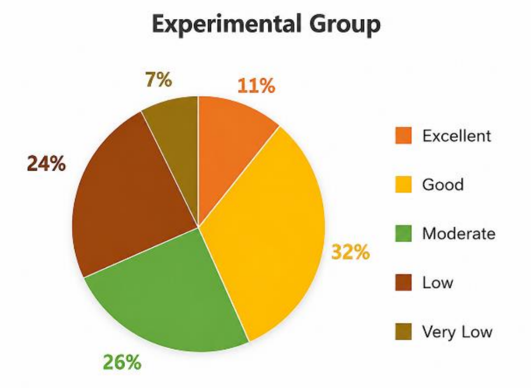

Figure 1. Problem-solving profile of the experimental group

Figure 1 shows that the experimental group was dominated by students in the Good (32%) and Moderate (26%) categories, followed by Low (24%), Excellent (11%), and Very Low (7%) categories. This distribution indicates that most students achieved moderate to high levels of problem-solving ability after participating in Crocodile Chemistry Lab-assisted PBL activities. The presence of students in the lower categories suggests that the intervention did not produce an identical effect for all learners. Differences in students' initial abilities, learning readiness, and familiarity with technology-supported learning may influence individual responses to instructional interventions [17], [23]. These findings indicate that additional scaffolding and longer exposure to simulation-assisted PBL may be required to support students with different levels of preparedness.

The problem-solving ability profile of the control group is presented in Figure 2. The figure illustrates that the control group showed a different distribution pattern, with the highest proportion of students in the Low category (26%), followed by Good (25%), Moderate (24%), Very Low (18%), and Excellent (7%). Compared with the experimental group, the control group demonstrated a higher proportion of students in the lower categories and a smaller proportion in the Excellent category. This pattern supports the statistical finding that students receiving Crocodile Chemistry Lab-assisted PBL achieved better problem-solving outcomes than those receiving the scientific approach. Although the scientific approach also involved observation, questioning, experimentation, discussion, and communication, the additional problem investigation and simulation activities in the experimental group may have provided greater opportunities for students to practice analysis, reasoning, and solution evaluation. Inquiry-based and technology-supported learning environments have been shown to promote students' engagement in scientific investigation and higher-order thinking processes [16], [23], [26].

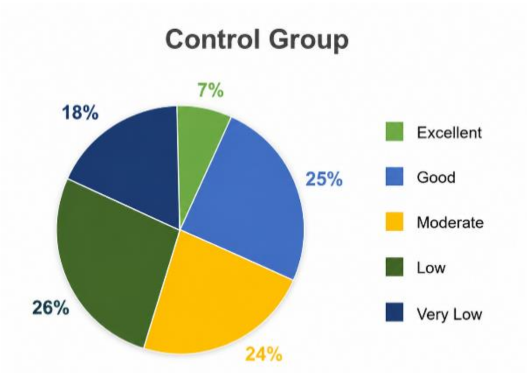

Figure 2. Problem-solving profile of the contol group

The analysis of problem-solving ability was further examined based on four indicators: (1) understanding and visualizing problems, (2) designing a solution strategy,

(3) implementing the strategy and finding a solution, and (4) reflecting on and assessing the effectiveness of the solution. The comparison of these indicators between the experimental and control groups is presented in Figure 3.

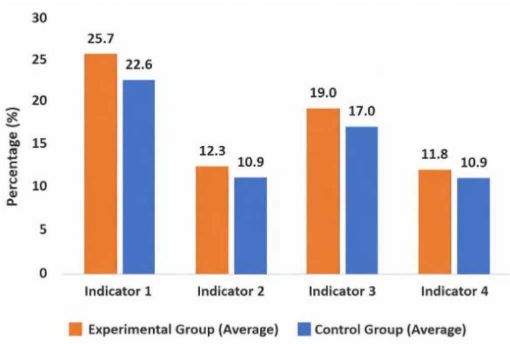

Figure 3. Percentage distribution of problem solving ability indicators

Figure 3 demonstrates that the experimental group achieved higher scores across all four problem-solving indicators compared with the control group. The largest difference was observed in Indicator 1 (understanding and visualizing problems), followed by Indicator 3 (implementing the strategy and finding a solution), Indicator 4 (reflecting on and assessing the effectiveness of the solution), and Indicator 2 (designing a solution strategy). The higher performance in Indicator 1 may be related to the use of contextual problems that encouraged students to identify relevant information and connect real-life phenomena with thermochemical concepts [18], [21]. The improvement in Indicator 2 suggests that PBL supported students in developing solution strategies through hypothesis formulation and collaborative investigation [19], [21].

Indicator 3 was strengthened through Crocodile Chemistry Lab activities, which enabled students to manipulate variables, analyze simulation results, and apply concepts during the problem-solving process [23], [26]. The higher achievement in Indicator 4 indicates that reflection and discussion activities in PBL supported students in evaluating solutions based on evidence and scientific reasoning [9], [11]. These findings suggest that Crocodile Chemistry Lab-assisted PBL supported the development of students' problem-solving processes, although the small effect size indicates the need for longer implementation and additional scaffolding to achieve stronger improvements.

4. Effect of Crocodile Chemistry Lab-Assisted PBL on Students' Scientific Attitude

The univariate analysis presented in Table 8 showed a significant difference in students' scientific attitude between the experimental and control groups ($F = 8.538$, $p = 0.004$, $\eta^2p = 0.057$). The experimental group achieved a higher posttest mean score ($M = 75.08$) compared with the control group ($M = 68.38$), indicating that students who received Crocodile Chemistry Lab-assisted Problem-Based Learning (PBL) demonstrated more favorable scientific attitudes after the intervention. The effect size indicated a small-to-moderate effect, suggesting that the intervention contributed positively to students' scientific attitudes, although the magnitude of change remained limited. This finding indicates that scientific attitude development may require sustained learning experiences because affective characteristics are influenced by repeated engagement in scientific activities.

The higher scientific attitude performance in the experimental group may be associated with the characteristics of PBL, which emphasizes problem investigation, evidence evaluation, collaboration, and reflection. The learning activities encouraged students to develop curiosity, academic honesty, reflective thinking, scientific skepticism, and responsibility through active involvement in solving contextual problems. Previous studies have shown that PBL can support scientific attitude development by engaging students in meaningful problem-solving activities and scientific discussions [11], [19]. The inquiry processes embedded within PBL, including investigation, interpretation of evidence, and reflection, may further strengthen students' scientific attitudes [13].

The integration of Crocodile Chemistry Lab provided additional support by allowing students to conduct virtual experiments, analyze simulation results, and construct explanations based on scientific evidence. These activities encouraged students to observe phenomena, evaluate information, and make decisions based on experimental results. Virtual laboratory environments have been reported to provide interactive learning experiences that support chemistry learning by connecting observation, experimentation, and conceptual understanding [23], [26]. The combination of PBL and simulation-based activities therefore created opportunities for students to practice scientific behaviors during thermochemistry learning. The distribution of students' scientific attitude categories in the experimental group is presented in Figure 4.

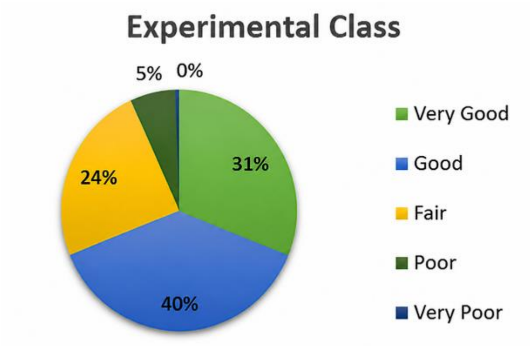

Figure 4. Scientific attitude profile of the experimental group

Figure 4 shows that most students in the experimental group achieved the Good category, indicating that the majority of students demonstrated positive scientific attitudes after participating in Crocodile Chemistry Lab-assisted PBL activities. However, some students remained in lower categories, suggesting that changes in scientific attitudes may vary among learners depending on prior experience, learning readiness, and adaptation to simulation-based instruction. These findings indicate that longer implementation periods and continuous scientific practice may be needed to achieve more consistent affective development.

The scientific attitude profile of the control group is presented in Figure 5. The figure illustrates the distribution of scientific attitude categories among students who received the scientific approach (5M). The control group also experienced scientific activities through observing, questioning, experimenting, and communicating; however, the experimental group showed a more favorable distribution pattern. The difference may be related to the additional opportunities provided by PBL-assisted simulation activities, where students were encouraged to investigate problems, discuss evidence, and reflect on their findings. Such inquiry-based engagement has been reported to contribute to the development of scientific attitudes by involving students in authentic scientific processes [11], [13].

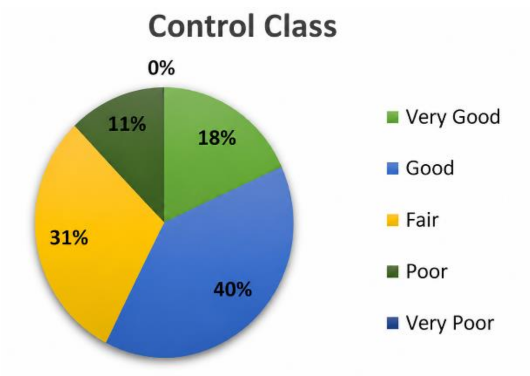

Figure 5. Scientific attitude profile of the control group

The comparison of scientific attitude indicators between groups is presented in Figure 6. The figure demonstrates that the experimental group achieved higher scores across all scientific attitude indicators, including curiosity, academic honesty, reflective thinking, scientific skepticism, and responsibility. The consistent improvement across indicators suggests that Crocodile Chemistry Lab-assisted PBL influenced multiple dimensions of scientific attitude rather than a single affective component. Curiosity and scientific skepticism were supported through problem investigation and evidence analysis, while academic honesty, reflective thinking, and responsibility were strengthened through reporting, discussion, and evaluation activities. Scientific attitudes are important components of chemistry learning because they influence how students engage with scientific inquiry, interpret evidence, and construct explanations [12]. The findings demonstrate that Crocodile Chemistry Lab-assisted PBL provides meaningful support for developing students' scientific attitudes, although the relatively small effect size indicates that longer and more intensive implementation may be required to produce stronger improvements.

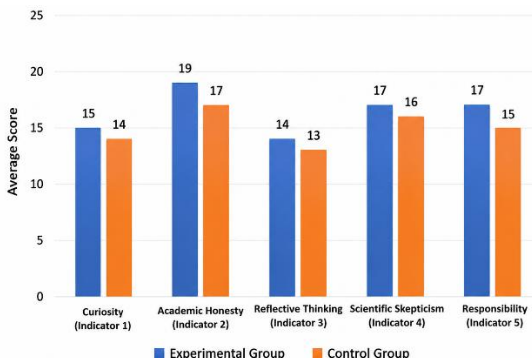

Figure 6. Profile of scientific attitude aspects

CONCLUSION

This study demonstrates that Problem-Based Learning assisted by Crocodile Chemistry Lab results in statistically significant but modest improvements in students' problem-solving ability and scientific attitude compared to a scientific approach. However, the magnitude of the observed effects was relatively small, indicating that the practical impact of the intervention remains modest. A key limitation of this study lies in the scope of implementation, which was restricted to a specific context and duration, potentially limiting the generalizability of the findings.

Practically, these results suggest that chemistry teachers may use simulation-assisted PBL as a complementary instructional strategy to promote more active and meaningful learning, particularly when supported by adequate student readiness and learning facilities.

Ethics Approval: This study was reviewed and approved by the Ethics Committee of Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta (Official Letter No. B/7320/UN34.13/TU.01/2025, issued on April 24, 2025).

Informed Consent: Written informed consent was obtained from all individual participants (and legal guardians for minor students) prior to data collection.

Author Contributions: D. Priyadi carried out the research implementation, including the design of learning activities, data acquisition, instrument administration, statistical analysis, and preparation of the initial manuscript draft. S. Suwardi provided academic supervision, contributed to research methodology, evaluated the validity of the instruments, interpreted the results, and revised the manuscript critically. Both authors contributed to the final review process and agreed with the published version of the manuscript.

Conflict of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this manuscript.

Declaration of Generative AI and AI-Assisted Technologies: During the preparation of this manuscript, the authors used AI-assisted tools to develop the graphical abstract and to support language proofreading. The authors remain fully responsible for the content, accuracy, interpretation, and conclusions presented in this article.

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