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The Effect of the Problem Based Learning Model on Critical Thinking in Basic Chemical Laws

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A B S T R A C T

Critical thinking is an essential 21st century skills to developed in chemistry education, particularly in the topic of Basic Chemical Laws, which require scientific reasoning. This research examines how the implementation of the Problem Based Learning approach impacts students critical thinking abilities within the context of Basic Chemical Laws. This quantitative study adopted a quasi experimental method with a non equivalent control group design, in which 72 tenth grade students from SMAN 95 Jakarta were selected through purposive sampling and assigned to an experimental class (n = 36) and a control class (n = 36). The instrument consisted of 17 critical thinking essay questions that had been validated by experts and empirically tested, with a Cronbach's Alpha reliability coefficient of 0.841. Data were analyzed using the Mann Whitney U test, normalized gain, Independent t-Test and effect sizes. The findings reveal a significant difference in critical thinking skills between the classes (p = 0.001), where the experimental class achieved a higher average N-Gain (0.30) than the control class (0.19). This model yielded a moderate positive impact, supported by a moderate effect size (Cohen's d = 0.642), proving that the PBL model successfully enhances students critical thinking skills in Basic Chemical Laws.

1. Introduction

In the 21st century, education requires students not only to master concepts but also to develop critical thinking skills for solving complex problems in daily life. However, Indonesian students critical thinking skills remain relatively low, as shown by data from the 2022 Programme for International Student Assessment (PISA) released by the Organisation for Economic Co operation and Development. The 2022 PISA data also reveal that Indonesian students scores in the science field reached only 366 points, far below the OECD average of 472 points. This indicates that students still struggle to reason, analyze, and critically evaluate information

(OECD, 2023). In order to develop skills for daily life, every student is expected to possess critical thinking skills as part of 21st century learning competencies, specifically through reflective and reasonable thinking, where choices about what to believe or do are prioritized. According to Ennis (1962), individuals who think critically are able to question assumptions, seek relevant evidence, consider others' perspectives, and draw well reasoned conclusions. These skills are highly relevant to the demands of chemistry education, where students must do more than simply memorize formulas, as they must be able to consider scientific evidence, evaluate hypotheses, and draw conclusions based on data.

A conventional, teacher centered approach still dominates chemistry instruction in schools, where instructional material is primarily delivered through teacher lectures. In this environment, students are left to passively listen and take notes on the material presented. Due to the lack of active student engagement caused by this situation, mastering materials and understanding concepts in chemistry become highly challenging, which ultimately manifests as low learning outcomes. This aligns with Setyorini's (2023) research, which found that chemistry instruction dominated by traditional methods generally leads to students being less active, causing them to struggle with understanding concepts and resulting in low learning outcomes. To encourage active student participation in thinking and problem solving, Problem Based Learning (PBL) can be implemented as an effective learning model. According to Arends (2012), this student centered model utilizes meaningful, real world problems where teachers act primarily as facilitators. Placed in small groups, students are given the opportunity to develop critical thinking skills, construct new knowledge, and solve real world challenges. Conceptually, there is a very close relationship between critical thinking skills and the Problem Based Learning (PBL) model. By providing learning experiences centered on contextual problems, this model encourages students to analyze relationships between variables, identify relevant information, evaluate data sources, and draw conclusions based on fact (Arends, 2012).Therefore, PBL serves as a pedagogical approach that directly facilitates the development of students critical thinking skills.

In chemistry learning, students are expected to do more than merely understand concepts; they must also be able to relate everyday phenomena to chemical principles, analyze experimental data, evaluate the validity of a statement, and draw scientific conclusions. This is because the abstract nature of chemistry has the potential to lead to misconceptions in understanding chemical concepts (Rahayu et al., 2023). Therefore, chemistry instruction needs to be designed to connect real world phenomena with scientific concepts. To effectively connect scientific concepts with real world phenomena, the basic chemical laws offer the ideal characteristics for instructional design. This foundational material encompasses Lavoisier's Law of Conservation of Mass, Proust's Law of Definite Proportions, Dalton's Law of Multiple Proportions, Gay Lussac's Law of Combining Volumes, and Avogadro's Law. These main materials on the fundamental laws of chemistry are not merely mathematical formulas that require students to memorize the wording of each law; rather, they involve connecting phenomena in everyday life, verifying their validity through experiments, interpreting experimental data, and

drawing conclusions based on scientific principles that can be analyzed (Rusmansyah et al., 2025)

The positive impact of Problem Based Learning (PBL) on student critical thinking has been widely documented. For instance, Kusasi (2024) developed a PBL based electronic module for this topic and reported an 81.15% N gain in students critical thinking. Similarly, Rohmah et al., (2024) integrated a hybrid PBL GI approach for the same material, yielding a moderate N-Gain of 0.479. Similar findings have also been reported in other topics. For example, Asmi et al., (2024) used interactive PBL e-modules to boost systematic problem solving (N-Gain = 0.48), while Mohamad et al (2023) found that a multi representational PBL framework significantly enhanced analytical and evaluative skills regarding buffer solutions. Even in biology, Hutabalian & Edi (2025) achieved a high category N-Gain of 0.71 on the excretory system using a similar problem centered design.While the positive impact of Problem Based Learning (PBL) on critical thinking is well documented, the majority of this research focuses on other chemistry topics. Research specifically examining the effect of PBL on critical thinking skills in the topic of Basic Laws of Chemistry remains limited and generally tests two variables simultaneously; consequently, it lacks depth and specificity regarding the critical thinking skills variable alone. Therefore, the specific effect of PBL on critical thinking skills still requires further study. Based on these gaps, this study aims to examine how the Problem Based Learning (PBL) model explicitly influences students' critical thinking skills within the context of the basic chemical laws. The findings of this study are expected to contribute to the literature on chemistry education and provide practical guidance for implementing PBL to improve students critical thinking skills, specifically by showcasing how problem centered frameworks can systematically sharpen student reasoning when tackling foundational chemical concepts

2. Methodology

A quasi experimental method with a non equivalent control group design was utilized in this research. This specific approach was selected to match the study's goal of evaluating how the Problem Based Learning (PBL) model affects students' critical thinking skills. Under this design, completely controlling every confounding variable was not feasible since the investigation relied on naturally formed, pre existing classes often referred to as intact groups (Creswell, 2018). The research population comprised 72 tenth grade students at SMAN 95 Jakarta during the even semester. Sampling was executed via a purposive approach, a method where participants are selected based on specific, predetermined criteria (Sugiyono, 2013) For this study, the selection criteria dictated that the classes must be managed by the same chemistry instructor, possess similar academic capabilities, and operate under the same instructional timetable. Consequently, the sample involved an experimental group (class X1; 13 males, 23 females) and a control group (class X5; 12 males, 24 females), each consisting of 36 students.

To execute the research design, a pretest was initially administered to both classes to assess their initial critical thinking skills. The experimental class was then taught using the PBL model, while the control class followed a conventional lecture-based format. After the treatment, a posttest was administered to both groups to measure changes in students reasoning abilities (Sugiyono, 2013). This study, the independent variable was the Problem Based Learning model, with critical thinking skills as the dependent variable, as outlined in Table 1.

Table 1. Research Design

Class	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_1	Y	O_2

Notes:
O : Pretest/Posttest
X : Treatment for the experimental class using the Problem Based Learning model.
Y : Treatment for the control class using conventional (Sugiyono, 2013)

Instrument

Instruments serve as essential tools deployed to gather data throughout the research process (Sahir, 2021). For this investigation, the measurement tools comprised a test instrument containing seventeen essay questions to evaluate the effectiveness of critical thinking development. Additionally, structured student worksheets were utilized to guide the Problem Based Learning (PBL) framework and stimulate student reasoning. The instrument was developed based on the critical thinking indicators proposed by Ennis (1962), which include focusing questions, identifying assumptions, evaluating the appropriateness of sources, inducing and evaluating the results of induction, observing and evaluating the results of discussions, interacting with others, and formulating conclusions and hypotheses.

The test instruments in this study underwent content validity and empirical validity assessments before they were deemed suitable for use in the research. Content validity was assessed through expert judgment by two validators: a chemistry lecturer and a chemistry education lecturer. Three main aspects assessed by the validators: (1) the alignment of the material with learning outcomes, critical thinking indicators, and student misconceptions regarding the basic chemical laws, (2) the technical construction of the essay questions, and (3) the rules of writing using language that is easy to understand. Based on the assessment results from both validators, the instrument was deemed suitable for research, with recommendation to improve two areas: first, regarding the content, adjustments should be made to the concepts in the basic chemical laws to prevent misconceptions among students; and second, regarding the language, the sentences in the questions should be simplified to make them easier for students to understand.

The instrument was then subjected to the field testing phase to assess its empirical validity and reliability. A validity test is used to determine whether an instrument

is capable of measuring what it is actually designed to evaluate (Arikunto, 2013), based on the validity test, seventeen essay questions were declared valid for this study and met the representativeness criteria for each sub indicator of critical thinking. Reliability measures the internal consistency of a research instrument, which is deemed dependable if its Cronbach's Alpha coefficient exceeds the 0.70 threshold. Upon analysis, the evaluation yielded a Cronbach's Alpha value of 0.841, this strong result places the instrument in the highly reliable category, demonstrating excellent consistency and stability for measuring student outcomes (Arikunto, 2013).

Data Collection

This research relied on primary quantitative data gathered directly from the research site. The dataset was compiled by measuring students critical thinking skills captured before and after the instructional model was implemented. The study was conducted over three in person sessions on the topic of the Basic Chemical Laws, with a learning time allocation of 3 × 45 minutes (135 minutes) per session. The three learning sessions covered the following topics: the first session focused on the Law of Conservation of Mass (Lavoisier's Law), the second session addressed on the Law of Definite Proportions (Proust's Law) and the Law of Multiple Proportions (Dalton's Law), and the third session concluded with the Law of Combining Volumes (Gay Lussac's Law) and Avogadro's Law. The summary of the data collection process, including the instruments and data sources used for both classes, is presented in Table 2.

Table 2. Data Collection

Data Type	Data Source	Number of Students
Pretest data on critical thinking skills	Written test (17 essay questions)	72 students (class X1 and class X5)
Posttest data on critical thinking skills	Written test (17 essay questions)	72 students (class X1 and class X5)

In the experimental class, instruction was conducted using the Problem Based Learning (PBL) model, which consists of five phases: Phase 1 involves orienting students to the problem (20 minutes), during which the teacher presents real world phenomena in the form of everyday problems to spark interactive questions and answers from students. Phase 2 organizes students for learning (10 minutes), where the teacher divides students into heterogeneous groups and distributes worksheets as a guide for formulating investigative questions. Phase 3 guides individual and group investigations (45 minutes), where students collaborate in groups to conduct simple experiments while the teacher acts as a facilitator who guides the information-gathering process. Phase 4 involves developing and presenting the results (35 minutes), during which student groups compile an experimental report based on their discussions and present it to the class to receive feedback from other groups. Phase 5 involves analyzing and evaluating the problem solving process (20 minutes), during which students draw conclusions from their discussions, and the teacher reinforces key concepts and reflects on the problem solving process to help

students avoid misconceptions (Arends, 2012). To support the implementation of this learning process, the experimental group was given worksheets aligned with the basic chemical laws, which served as tactical learning tools to stimulate students' reasoning skills. In contrast, the control group followed a traditional pedagogical approach, in which instruction focused primarily on expository lectures, class discussions, and routine problem solving exercises.

Data Analysis

A quantitative approach utilizing inferential statistical analysis techniques was adopted in this study. The data analysis primarily focused on processing students test scores to compare learning achievements between the experimental class instructed through the Problem Based Learning (PBL) model and the control class, which followed a conventional format (Sugiyono, 2013). Prerequisite tests were executed to verify that the dataset satisfied all underlying statistical assumptions. These preliminary evaluations included a normality test to confirm a normal distribution and a homogeneity test to ensure equal variances between the experimental and control groups (Sugiyono, 2013). Because certain raw data sets violated the normality assumption and displayed unequal variances, a nonparametric statistical hypothesis test was deployed using the Mann-Whitney U test. Conversely, the normality and homogeneity assumptions were fully met when evaluating the N-Gain scores; hence, a parametric independent samples t-test was utilized for further hypothesis testing. Finally, an effect size analysis was calculated to determine the magnitude of the impact that the Problem Based Learning (PBL) model had on students critical thinking skills.

3. Results and Discussion

The experimental class received instruction using the Problem Based Learning (PBL) model across three learning meetings on the topic of Basic Chemical Laws, while the control class was taught using conventional teacher centered instruction. The implementation of PBL followed five learning phases, namely orienting students to the problem, organizing students for learning, guiding individual and group investigations, developing and presenting solutions, and analyzing and evaluating the problem solving process (Arends, 2012). During the learning process, students were presented with contextual problems through student worksheets (LKPD) and worked collaboratively in small groups to investigate the problems, formulate hypotheses, analyze the findings, present their solutions, and draw conclusions based on scientific evidence (Asmi et al., 2024). These learning activities actively engaged students in constructing knowledge and developing critical thinking skills through collaborative problem solving (Suci, 2025). Following the implementation of the learning treatment, the research data were analyzed using descriptive statistical tests to determine the distribution of students' pretest and posttest critical thinking scores. The results of the descriptive statistical analysis are presented in Table 3.

Table 3. Descriptive Statistical Analysis of Critical Thinking

Data Group	Sampel	Lowest Score	Highest Score	Mean	Standar Deviation
Experimental Pretest	36	13,24	35,29	22,95	6,10
Experimental Posttest	36	34,88	55,47	46,11	6,13
Control Pretest	36	0	35,94	15,09	9,85
Control Posttest	36	15,35	56,53	33,04	8,68

Data from Table 3, the pretest results clearly show that students in both the experimental and control classes started with relatively low critical thinking skills. After the lessons were completed, both groups managed to improve their average scores on the posttest. The experimental class that received instruction through the Problem Based Learning (PBL) model achieved a considerably higher posttest mean score than the control class. After conducting descriptive statistical tests, a normality test was performed on the critical thinking indicators to determine whether the distribution of critical thinking data in both classes was normal or not, as shown in Table 4.

Table 4. Normality Test Results

Class	Shapiro-Wilk		
	Statistic	(df)	Significance
Experimental Pretest	0,949	36	0,097
Experimental Posttest	0,929	36	0,023
Control Pretest	0,959	36	0,198
Control Posttest	0,978	36	0,664

The normality test revealed that the pretest data for the experimental group (0.097), the control group (0.198), and the control group's posttest (0.664) were normally distributed, as their significance values remained well above 0.05. In contrast, the posttest results for the experimental cohort yielded a significance value of 0.023. Because this value is less than 0.05, the assumption of normality for this final dataset was not met. The second prerequisite analysis performed was the homogeneity test of the critical thinking scores for both the experimental and control classes. This analysis aimed to determine whether the data variances between the two groups were equal, as shown in Table 5.

Table 5. Homogeneity Test Results

	Levene Statistic	df1	df2	Significance
Based on Mean	9.460	1	70	.003
Based on Median	7.076	1	70	.010
Based on Median and with adjusted df	7.076	1	58.293	.010
Based on trimmed mean	8.997	1	70	.004

The homogeneity test result was 0.003 < 0.05, so it can be concluded that the two datasets have different variances, or are heterogeneous. A nonparametric statistical test was then conducted because some data groups did not meet the normality assumption and the data variances were not homogeneous. To test for differences in the effectiveness of the treatment between groups, the Mann-Whitney U test was used to compare the final pretest scores of the experimental and control classes before the treatment and to compare the final posttest scores of the experimental and control classes after the treatment (Sugiyono, 2013). The statistical output for the initial pretest comparison is shown in Table 6.

Table 6. Pretest Results of the Mann-Whitney U Test

	Result
Mann-Whitney U	338.000
Wilcoxon W	1004.000
Z	-3.494
Asymp. Sig. (2-tailed)	.000

The results of the hypothesis test based on critical thinking skills data showed a significance value of $p < 0.001$. Therefore, H_0 was rejected and H_1 was accepted, indicating a significant difference in initial critical thinking skills between the experimental and control groups prior to the intervention. Although the pretest scores indicated differences in students initial abilities, improvements in critical thinking skills were evaluated using normalized gain (N-Gain), which assesses the effectiveness of learning based on changes in scores from the pretest to the posttest. The use of N-Gain is considered appropriate because it takes students' initial abilities into account when evaluating learning gains. Therefore, the effectiveness of the Problem Based Learning model is not interpreted solely based on a comparison of pretest scores when the two groups have different initial abilities (Hake, 1998). To evaluate the post intervention differences between the groups, the final posttest scores were analyzed using the Mann-Whitney U test, with the results summarized in Table 7. The hypothesis test based on the posttest critical thinking scores yielded a significance value of 0.000, which was lower than the 0.05 significance level. Therefore, H_0 was rejected and H_1 was accepted, indicating a statistically significant difference in the mean critical thinking scores between the experimental and control groups after the intervention.

Table 7. Posttest Results of the Mann-Whitney U Test

	Result
Mann-Whitney U	140.000
Wilcoxon W	806.000
Z	-5.729
Asymp. Sig. (2-tailed)	.000

This empirical evidence, supported by the Mann-Whitney U test, demonstrates that the implementation of the Problem Based Learning (PBL) model significantly improved students' critical thinking skills in learning Basic Chemical Laws, offering a superior alternative to conventional pedagogical approaches. Although this test showed a clear difference in ability between the two classes, this analysis

alone could not describe the magnitude of individual improvement in each class. Therefore, an N-Gain analysis was subsequently conducted to evaluate the effectiveness of the instructional models by assessing the ratio of actual gain to the maximum potential gain (Hake, 1998). The comprehensive results of the descriptive statistical analysis for both groups' N-Gain scores are presented in Table 8.

Table 8. Descriptive Analysis of N-Gain

Data Group	Sampel	Lowest Score	Highest Score	Mean	Standar Deviation
N-Gain Experimental Class	36	0,08	0,47	0,30	0,08
N Gain Control Class	36	0,06	0,40	0,19	0,09

The empirical data reveals that the experimental class achieved a higher mean N-Gain score (0.30) compared to the control group (0.19). According to the criteria by Hake (1998), the pretest to posttest progression in the experimental group is classified as moderate ($0,30 < g \leq 0,70$), while the control group's remains in the low tier ($g \leq 0,30$). underscoring the effectiveness of the PBL model over conventional approaches. These results reflect the empirical evidence by Jusma et al., (2026), where the experimental class achieved superior, moderate N-Gain performance while the control group remained low. Consequently, the specific N-gain observed in this study indicates underlying challenges, including students' low initial ability, limited class hours, and the adjustment period required to adapt to an active problem-solving environment. To determine whether the computed N-Gain scores followed a normal distribution, the data from both groups were subjected to a Shapiro-Wilk normality test, the complete breakdown of which is presented in Table 9.

Table 9. N-Gain Normality Test

Class	Shapiro-Wilk		
	Statistic	(df)	Significance
Experimental N-Gain	0,972	36	0,489
Control N-Gain	0,965	36	0,300

Based on the results of the normality test, the significance values for N-Gain were 0.489 for the experimental class and 0.300 for the control class. Since both significance values are greater than 0.05, the N-Gain data for the experimental and control classes are normally distributed. To determine whether the experimental and control groups exhibited homogeneous variances, a homogeneity assessment was performed on the N-Gain dataset. The empirical results of this analysis are detailed in Table 10.

Table 10. N-Gain Homogeneity Test

	Levene Statistic	df1	df2	Significance
Based on Mean	.655	1	70	.421
Based on Median	.657	1	70	.420

Based on Median and with adjusted df	.657	1	69.522	.420
Based on trimmed mean	.616	1	70	.435

Based on the results of the homogeneity test, the significance value for N-gain was 0.421 > 0.05. These results indicate that the variances of the N-Gain data for the experimental and control classes are homogeneous. Following the confirmation that the N-Gain dataset meets both normality and homogeneity assumptions, a parametric Independent Sample t-Test was performed. This approach was utilized to evaluate the significance of mean variances between the two distinct groups (Sugiyono, 2013), with the resulting data presented in Table 11.

Table 11. N-Gain Hypothesis Test

	T	**df**	**Significance**
N gain in critical thinking skills	4.300	70	.000

Based on the statistical analysis, the hypothesis test yielded a significance level of 0.000, falling well below the 0.05 threshold. Consequently, H_0 was rejected and H_1 was accepted, confirming a statistically significant difference in how much students improved their critical thinking skills between the experimental class and the control class. To determine the magnitude of the effect of implementing the Problem Based Learning (PBL) model on critical thinking skills, an effect size analysis was conducted. The effect size values are shown in Table 12.

Tabel 12. Effect Sizes

	D
Cohen's	0,624

To complement the statistically significant findings, the effect size was calculated using Cohen's d, yielding a value of 0.624 with a 95% confidence interval (CI) ranging from 0.151 to 1.098. According to the criteria by Cohen (1988), where a value within the range of $0.50 < d \leq 0.80$ is categorized as a medium effect size. This finding indicates that the implementation of the Problem Based Learning (PBL) model results in a meaningful improvement in students' critical thinking skills within the context of basic chemical laws, as reflected by both the statistical significance and the medium magnitude of the observed effect.

The N-Gain analysis per indicator was conducted based on critical thinking skills as defined by Ennis (1962), encompassing question focusing, assumption identification, source reliability assessment, induction development and evaluation, observation execution and appraisal, social interaction, and conclusion drawing. The results of the analysis showed that, for nearly all critical thinking indicators, the experimental group achieved superior growth compared to the control group across almost all assessed sub skills. The complete distribution of these N-gain percentages per indicator is displayed in Figure 1.

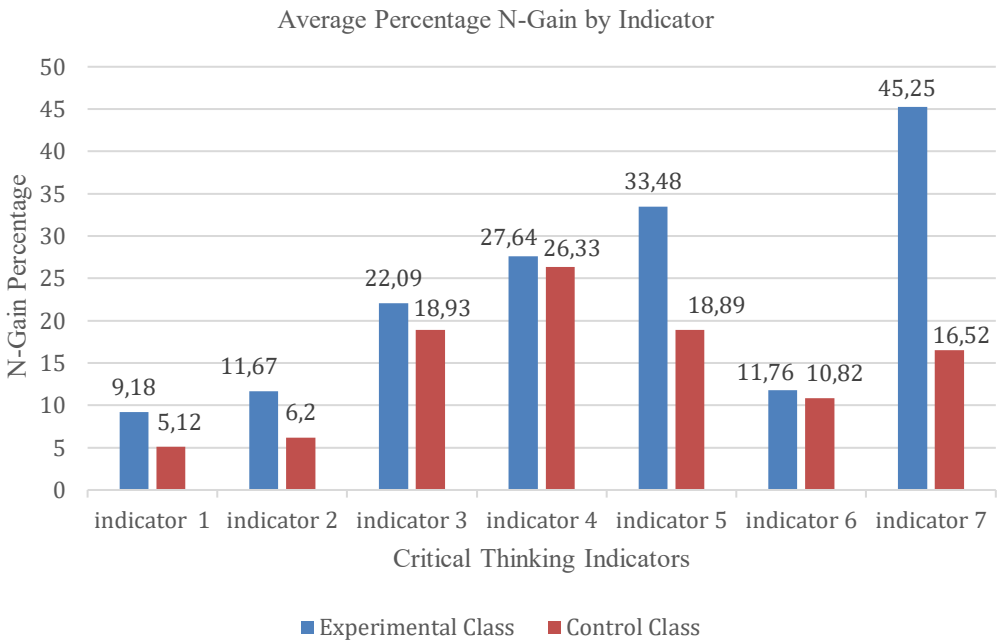

Figure 1. Percentage N-gain by Indicator

The first indicator, which measures the ability to focus questions, showed an N-Gain increase of 9.18% for the experimental class and 5.12% for the control class. Although the experimental class showed a greater increase, this indicator recorded the lowest gain among all critical thinking indicators, suggesting that students still struggle to identify problems when first confronted with contextual phenomena. During the problem orientation phase of the PBL model, students observed paper burning and rusting nails through worksheets. When comparing the masses before and after each process, students explained that the mass of the paper decreased due to combustion, while the mass of the nail increased due to reactions with substances in the air. Although these explanations show that students recognized observable phenomena, their answers remained descriptive rather than focusing on the underlying scientific problem. Consequently, students still faced challenges in formulating relevant scientific questions at the beginning of the process.

According to Ennis (1962), focusing questions are an initial component of critical thinking that determine the direction of subsequent reasoning and problem solving processes. Similarly, Arends (2012) the problem orientation stage is intended to create cognitive conflict by presenting authentic and meaningful problems that cannot be solved through memorization alone. During this stage, students are encouraged to identify what is already known, determine what information is still needed, and formulate questions that will guide the subsequent investigation. In this study, although students were able to describe the observable phenomena, many were still unable to identify the underlying scientific problem. In line with the findings of Sirait & Maulida (2023), who noted that students are often not yet accustomed to learning activities that demand critical thinking, they emphasize that worksheets as guides for contextual learning integrated with the Problem Based

Learning model provide meaningful opportunities for students to gradually develop critical thinking skills through active inquiry and problem solving activities.

The second indicator, identifying assumptions, showed an 11.67% increase in N for the experimental class and a 6.20% increase for the control class. According to Ennis (1962), identifying assumptions involves students ability to recognize underlying ideas and formulate logical hypotheses based on prior knowledge before drawing conclusions. For example, when presented with water (H_2O) and hydrogen peroxide (H_2O_2) phenomena, students formulated the question, "Why do hydrogen peroxide and water have different properties even though both consist of the same elements?" Students then hypothesized that the differing number of oxygen atoms results in distinct molecular structures and chemical properties. This demonstrates that students were able to identify assumptions by integrating their prior knowledge of atomic composition with logical reasoning before proceeding to the experimental phase.

According to Arends (2012), after students are introduced to an authentic problem, the organizing phase requires them to activate their prior knowledge, define the problem, identify what information is needed, and propose a tentative explanation before beginning their investigation. Rather than receiving a direct explanation from the teacher, students are encouraged to collaboratively develop initial assumptions through discussion. In this study, students formulated hypotheses based on the differences in atomic composition between H_2O and H_2O_2, demonstrating that they were able to connect prior knowledge with logical reasoning before verifying their assumptions through experiments.This learning process helped students develop the ability to identify assumptions, which is an essential component of critical thinking. Similar findings were reported by Kusasi (2024), who found that the implementation of Problem Based Learning in the topic of the basic chemical laws promoted students critical thinking skills by engaging them in problem analysis, hypothesis formulation, investigation, and evidence based reasoning.

The third indicator, which evaluates the appropriateness of sources, showed an increase of 22.09% in the experimental class, compared to 18.93% in the control class. According to Ennis (1962), this indicator refers to students ability to evaluate the credibility and appropriateness of information before using it as a basis for drawing conclusions. The improvement in this indicator was supported by the guided independent and group investigation phases within the Problem Based Learning (PBL) model. During this phase, students conducted an experiment on the Law of Conservation of Mass using a bottle tightly sealed with a balloon, with vinegar and baking soda as reactants. However, the masses measured before and after the reaction were not the same. To verify this finding, students compared their experimental results with an instructional video demonstrating the same experiment using laboratory equipment, in which an erlenmeyer flask was tightly sealed with a stopper to maintain a closed system, resulting in the same mass before and after the reaction. Through this activity, students did not simply accept the experimental results at face value, but rather engaged in critical thinking to evaluate the relevance and credibility of various sources of evidence by comparing results obtained under

different experimental conditions. Arends (2012), explains that the investigation phase encourages students to gather information from multiple sources, compare evidence from different sources, and evaluate the credibility of the information before using it to solve the problem. Students are expected not only to collect data but also to determine whether the available evidence is credible, relevant, and sufficent to support a conclusion. In this study, students compared their own experimental findings with evidence obtained from an instructional video using laboratory equipment. This comparison enabled students to recognize that differences in experimental conditions influenced the results, thereby strengthening their ability to evaluate the credibility and relevance of scientific evidence before drawing conclusions. This finding is consistent with Rumanti & Christy (2026), who reported that Problem Based Learning encourages students to analyze problems and evaluate information, which contributes to the development of critical thinking skills.

The fourth indikator conducting induction and considering the results of induction showed an increase N-Gain of 27.64% in the experimental class and 26.33% in the control class. According to Ennis (1962), this indicator refers to students ability to formulate assumptions, make generalizations, and draw conclusions based on evidence obtained through the inquiry process. The improvement in this indicator was supported by the guided individual and group inquiry phases within the Problem Based Learning model. During this phase, students conducted investigations to collect data that could serve as a basis for drawing conclusions. Students designed experiments to investigate the relationship between the amount of baking soda and the volume of carbon dioxide (CO_2) gas produced by its reaction with vinegar. In this activity, students set the amount of baking soda and vinegar as independent variables, the size of the balloon as the volume of gas produced, and developed experimental procedures to obtain the required data. The group of students explained that they used varying amounts of baking soda to determine the effect of the amount of baking soda and vinegar on the amount of CO_2 gas produced, and that the size of the balloon served as an indicator of the volume of gas formed. This demonstrates that the students were able to identify variables, design a logical investigative procedure, and relate experimental data to their assumptions. Through this activity, students were not only involved in collecting experimental data but were also trained to evaluate evidence before drawing conclusions.

This activity is in line with Problem Based Learning (PBL), according to Arends (2012) the inquiry phase places students in the role of active problem solvers who are responsible for planning inquiry activities, selecting appropriate procedures, collecting evidence, and interpreting data to solve authentic problems. Through this process, students gradually identified patterns in the collected data, formulated generalizations, and constructed explanations supported by empirical evidence. In this study, students independently identified variables, designed experimental procedures, and interpreted the relationship between the amount of baking soda and vinegar and the volume of CO_2 produced. This inquiry process directly supports the development of inductive reasoning because students draw conclusions from the evidence they collect themselves, rather than relying solely on the teacher's explanations. These findings are also supported by Suci, (2025), who reported that

the implementation of PBL has a positive effect on students critical thinking skills by actively involving them in the problem solving process. Furthermore, Mustikazahra et al., (2025) found that PBL based learning can enhance students' critical thinking skills through problem analysis activities and active engagement during the learning process. Therefore, the simple experiments conducted in this study provide students with the opportunity to build knowledge based on real evidence.

The fifth indikator observing and considering the results of observations showed an N-Gain of 33.48% in the experimental class and 18.89% in the control class. According to Ennis (1962), this indicator refers to students ability to carefully observe phenomena, identify relevant information, and consider the results of their observations as evidence in the reasoning process. Improvements in this indicator were supported by the artifact development and presentation stage in the Problem-Based Learning (PBL) model. During this stage, students analyzed and presented the results of experiments related to the formation of carbon dioxide (CO_2) gas through the reaction between vinegar and baking soda, using varying amounts of baking soda and vinegar.

Based on observations, the students identified the changes that occurred during the reaction, such as the formation of gas bubbles and the expansion of the balloon due to the buildup of CO_2 gas. The students also compared the sizes of the balloons in each treatment and recorded the differences in gas volume produced when using different amounts of baking soda and vinegar. One group explained that "The balloon inflates because CO_2 gas is produced from the reaction between vinegar and baking soda. The balloon that used more baking soda expanded more because more gas was formed, and the balloon that used less baking soda expanded less because less gas was formed." This demonstrates that students were able to observe experimental phenomena, identify differences among the treatments, and use their observations to explain the relationship between the amount of reactants used and the gas produced.

According to Arends (2012), states that the stage of developing and presenting artifacts requires students to organize, interpret, and communicate the evidence obtained during the investigation. Rather than merely reporting observations, students are expected to transform empirical findings into meaningful scientific explanations supported by evidence. In this study, students interpreted differences in balloon size as evidence of variations in carbon dioxide production and used these observations to explain the relationship between the quantities of reactants and the gas produced. This process helped strengthen students ability to interpret observational evidence as a basis for scientific reasoning. These findings are also supported by Suci (2025), who reported that the implementation of PBL positively influences students critical thinking skills by engaging them in problem centered learning and active inquiry.

The sixth indikator interacting with others showed an N-Gain of 11.76% in the experimental class and 10.82% in the control class. According to Ennis (1962), this indicator refers to students ability to communicate ideas, provide explanations,

respond to questions, and consider others opinions during discussions. Improvements in this indicator were supported by the stage of presenting work results within the Problem Based Learning (PBL) model. After conducting experiments and analyzing research data, students compiled their findings into group reports and presented their work through presentations. Through these presentations, students share their observations, data analyses, and conclusions derived from the investigative process. Students also engage in discussions with other groups by asking questions, offering responses, and expressing opinions based on evidence gathered during the experiments. These activities provide students with opportunities to communicate their views, defend their arguments, and build understanding through interaction with others.

However, these indicators showed a similarly low level of improvement between the experimental and control classes. This was due to the students' limited experience in engaging in scientific discussions and actively communicating their opinions. During the presentation activities, some students were still hesitant to express their opinions, ask questions, or respond to arguments from other groups because they had previously been more accustomed to teacher centered learning. According to Arends (2012), collaborative discussion is one of the essential characteristics of Problem Based Learning because knowledge is constructed through dialogue, argumentation, and shared inquiry. During presentations and classroom discussions, students are encouraged to justify their ideas using scientific evidence, respond to alternative viewpoints, and refine their understanding through interaction with peers. Although the improvement in this indicator was relatively limited, the discussion activities nevertheless provided meaningful opportunities for students to practice scientific communication and collaborative reasoning, which are fundamental components of critical thinking. This finding is also supported by Rusyati & Rustaman (2025), who explain that the implementation of Problem Based Learning encourages students' active engagement in the learning process and supports the development of critical thinking skills through problem-solving activities.

The seventh indikator formulating and evaluating conclusions showed an N-Gain of 45.25% in the experimental class and 16.52% in the control class. The greatest improvement in this indicator was due to students' engagement in analyzing empirical evidence after conducting experiments and discussing the data obtained. This enabled them to formulate conclusions consistent with scientific concepts. Through this activity, students analyze experimental data, compare their findings with the concepts of the basic chemical laws, and draw conclusions to answer the research question presented at the beginning of the lesson. Students are encouraged to ensure that their conclusions are based on the evidence obtained from the experiment and supported by scientific concepts.

This process trains students to evaluate information and make logical judgments based on evidence. Arends (2012), explains that the final stage of Problem Based Learning involves analyzing both the problem solving process and the proposed solution through reflection and evaluation. Students are expected to evaluate whether the evidence they collected sufficiently supports their conclusions,

evaluate the quality of their reasoning, and consider alternative explanations when necessary. In this study, students analyzed the experimental evidence, compared their findings with the concepts of the basic chemical laws, and formulated conclusions that were supported by empirical data. This reflective evaluation process contributed to the substantial improvement observed in students ability to formulate and evaluate evidence based conclusions. These findings are also supported by Andini et al (2025), who reported that the implementation of Problem Based Learning significantly improved students critical thinking skills by encouraging active engagement in analyzing problems and evaluating information during the learning process.

The improvement in students critical thinking skills was supported by the implementation of each Problem Based Learning (PBL) phase, guided by the LKPD. In the problem orientation stage, students were introduced to contextual chemical problems, encouraging them to identify issues, formulate questions, and integrate prior knowledge before the investigation. During the organization and investigation stages, students collaborated to analyze problems, formulate hypotheses, and conduct simple experiments or discussions. Analyzing these investigation results trained students to identify assumptions, evaluate evidence, and develop data-based reasoning. Finally, during the presentation and evaluation stages, students presented their solutions, responded to peers, and discussed the accuracy of their findings. These activities encouraged students to present arguments, evaluate different perspectives, and draw conclusions based on scientific reasoning, ultimately contributing to the enhanced critical thinking skills in the experimental class.

These findings are consistent with the theoretical perspective of the Problem Based Learning (PBL) model, which emphasizes active student involvement in constructing knowledge through problem solving activities. According to Hmelo-Silver (2004), problem based learning encourages students to construct knowledge through investigation and problem solving, thereby supporting the development of higher order thinking skills. These results are also supported by Jusniar et al., (2024), who reported that PBL can improve chemistry students' critical thinking skills, particularly in interpretation, analysis, inference, deduction, and evaluation. Similarly, Wardana & Aznam (2026) emphasized that PBL plays an important role in strengthening critical reasoning in chemistry education. This model is particularly relevant for basic chemical laws because it encourages students to connect abstract concepts with real world phenomena rather than relying solely on memorization.

4. Conclusion

Based on the research findings, the Problem Based Learning (PBL) model positively affects students critical thinking skills in learning Basic Chemical Laws, thereby answering the research question affirmatively. Through identifying problems, conducting investigations, discussing findings, evaluating information, and drawing evidence-based conclusions, students actively engage in scientific

reasoning. These findings indicate that PBL is an effective instructional approach for enhancing critical thinking skills in chemistry learning, particularly on the topic of Basic Chemical Laws. From a practical perspective, chemistry teachers are encouraged to integrate Problem Based Learning into classroom instruction by designing contextual learning activities that actively involve students in problem solving and scientific reasoning. Such learning experiences can help students connect abstract chemistry concepts with real-life phenomena while fostering critical thinking skills through collaborative investigation and evidence-based discussion. This study was limited to implementing Problem Based Learning in the topic of Basic Chemical Laws, involving tenth-grade students from a single senior high school. Future studies are recommended to investigate the effectiveness of Problem Based Learning in other chemistry topics, such as chemical equilibrium, reaction rates, acid-base, electrochemistry, or thermochemistry, as well as with students from different educational levels and larger, more diverse samples. Such studies are expected to provide broader evidence regarding the effectiveness of Problem Based Learning in improving students critical thinking skills across various chemistry learning contexts.

Reference

Andini, R. N., Utaya, S., & Suharto, Y. (2025). The Effect of Spatial Problem Based Learning Models on Critical Thinking Skills as Seen from the Eco-Literacy of High School Students. *Journal of Educational Sciences*, *9*(6). https://doi.org/10.31258/jes.9.6.p.6394-6413

Arends, R. I. (2012). *Learning to Teach, TENTH EDITION* (10th ed.). McGraw-Hill Education.

Arikunto, S. (2013). *Prosedur Penelitian : Suatu Pendekatan Praktik*. PT. Rineka Cipta.

Asmi, A., Silaban, S., & Silaban, R. (2024). Developing An Interactive Chemistry E-module Based on Problem-based Learning to Improve Critical Thinking Skills of High School Students. *Jurnal Paedagogy*, *11*(1), 94. https://doi.org/10.33394/jp.v11i1.9875

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Lawrence Erlbaum Associates.

Creswell, J. W. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approache* (5th ed.). Sage Publications.

Ennis, R. H. (1962). *Ideal critical thinkers are disposed to* (Vol. 26). Philosophy Documentation Center.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Hmelo-Silver, C. E. (2004). Problem-Based Learning: What and How Do Students Learn? *Education Psychology Review*, *16*(3). https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hutabalian, P. M., & Edi, S. (2025). Pengaruh Model PBL terhadap Kemampuan Berpikir Kritis Siswa Materi Sistem Ekskresi Kelas XI IPA SMAS Budi

Mulia Pematangsiantar. *Jurnal Pendidikan MIPA*, *15*(3), 1070–1076. https://doi.org/10.37630/jpm.v15i3.3221

Jusma, Nasution, R., Akhmad, & Masitah. (2026). Pengaruh Penggunaan Problem Based Learning (PBL) Terhadap Metakognitif dan Hasil Belajar Kognitif Siswa Kelas VIII di SMP Negeri 37 Samarinda pada Materi Sistem Ekskresi Manusia. *Jurnal Biology Science & Education*, *15*. https://doi.org/10.33477/bs.v15i1.7491

Jusniar, Syamsidah, Sakinah, Z., Munthalib, & Sentot, K. (2024). Effectiveness of Problem-Based Learning to Improve Critical Thinking Ability of Chemistry Students on Acid-Base Material. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 6464–6472. https://doi.org/10.29303/jppipa.v10i9.8434

Kusasi, M. (2024). Development of e-modules of basic laws of chemistry based on problem- based learning to improve critical thinking skills. *Jurnal Inovasi Teknologi Pendidikan*, *11*(4).

Mohamad, E., Paputungan, M., & Dahiba, A. (2023). The Effect of The Problem-Based Learning (PBL) Model with a Multi-Representation Approach on Students' Critical Thinking Skills in The Buffer Solution Concept. *E3S Web of Conferences*, *400*, 4001. https://doi.org/10.1051/e3sconf/202340004001

Mustikazahra, F., Novia, H., & Aviyanti, L. (2025). Learning Model in Improving Students' Critical Thinking Skills. *Journal of Educational Sciences*, *9*(4). https://doi.org/10.31258/jes.9.6.p.6394-6413

OECD. (2023). PISA 2022 Results (Volume I): The State of Learning and Equity in Education. In *PISA*. OECD Publishing. https://doi.org/10.1787/53f23881-en

Rahayu, D. S., Yanti, M., & Lestari, A. (2023). Students' Chemistry Multiple Representation Ability in Voltaic Cell Materials. *Journal of Tropical Chemistry Research and Education*, *5*(1), 44–53. https://doi.org/10.14421/jtcre.2023.51-06

Rohmah, A. A. L., Erman, E., & Ilhami, F. B. (2024). Penerapan Group Investigation dalam Problem Based Learning untuk Meningkatkan Kemampuan Pemecahan Masalah pada Pencemaran Lingkungan. *Jurnal Basicedu*, *8*(5), 3613–3620. https://doi.org/10.31004/basicedu.v8i5.8468

Rumanti, N. D., & Christy, K. (2026). The Effect of Problem-Based Learning Supported by Augmented Reality and Learning Motivation on the Critical Thinking Skills of Elementary School Students. *Journal of Educational Sciences*, *10*(6). https://doi.org/10.31258/jes.10.6.p.119-131

Rusmansyah, R., Yanti, H., Saadi, P., Mahdian, M., Rusmanayanti, A., & Kusuma, A. E. (2025). Literature Review: Application of the Problem-Based Learning (PBL) Model to Critical Thinking Skills in Chemistry Learning Materials. *Journal of Mathematics Science and Computer Education*, *5*(1), 43. https://doi.org/10.20527/jmscedu.v5i1.14779

Rusyati, L., & Rustaman, N. (2025). Teachers' Perception on the Implementation of Problem-Based Learning Integrated with Predict Observe Explain on Students'. *Journal of Educational Sciences*, *9*(5). https://doi.org/10.31258/jes.9.5.p.3281-3292

Sahir, S. (2021). *Metodologi Penelitian*. KBM INDONESIA.

Setyorini, N. (2023). Meningkatkan Hasil Belajar Kimia Materi Redoks Melalui Model Pembelajaran PBL Berbasis Video. *Jurnal Pendidikan dan Profesi*

Keguruan, *3*. https://doi.org/e-ISSN 2809-4492, p-ISSN 2809-4794

Sirait, J. V., & Maulida, R. (2023). Needs Analysis of The Development STEM-PjBL Based LKPD To Train Students' Critical Thinking Skills. *Journal of Educational Sciences*, *7*(3), 488. https://doi.org/10.31258/jes.7.3.p.488-498

Suci, A. (2025). The Effect of PBL Model on Students' Critical Thinking Ability in View of Adversity Quotient (AQ). *Journal of Educational Sciences*, *9*(4). https://doi.org/10.31258/jes.9.4.p.2639-2646

Sugiyono. (2013). *Metode Penelitian Kuantitatif, Kualitatif Dan R&D*. ALFABETA, CV.

Wardana, F., & Aznam, N. (2026). The influence of problem-based learning on student's critical thinking skills in chemical equilibrium. *Indonesian Journal of Chemical Education*, *2*(2). https://doi.org/10.21831/ijce.v2i2.92283

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