

Experimental Study: The Effect of Problem-Based Learning on Students' Chemistry Learning Outcomes in Thermochemistry Concepts

Sony Hidayat¹, and Olaitan Abiodun Josiah²

¹Department of Chemistry Education, Universitas Islam Negeri Syarif Hidayatullah Jakarta, Banten, Indonesia

²Department of Chemistry, Adeniran Ogunsanya College of Education, Lagos, Nigeria

Article Info

Article history:

Received Feb 13, 2026

Revised Mar 15, 2026

Accepted Apr 3, 2026

OnlineFirst Apr 6, 20xx

Keywords:

Chemistry Education
Experimental Study
Learning Outcomes
Problem-Based Learning
Thermochemistry

ABSTRACT

Purpose of the study: This study aims to determine the effect of the Problem-Based Learning model on students' chemistry learning outcomes, specifically on thermochemistry concepts, by comparing the performance of students taught using problem-based learning and those taught using conventional learning methods.

Methodology: This study used a quasi-experimental method with a nonequivalent control group design. The sample was selected using purposive sampling. Data were collected using multiple-choice test instruments. Data analysis techniques included Liliefors normality test, Fisher homogeneity test, and t-test at a significance level of 0.05.

Main Findings: The results showed that there was a significant difference in learning outcomes between students taught using the Problem-Based Learning model and those taught using conventional methods. Students in the experimental group demonstrated higher achievement in thermochemistry concepts compared to the control group after the learning process.

Novelty/Originality of this study: This study provides new insights by applying an experimental design to specifically examine the effect of Problem-Based Learning on thermochemistry learning outcomes. It integrates contextual problem-solving with conceptual understanding, offering a more meaningful learning approach and contributing to the development of innovative chemistry teaching strategies.

This is an open access article under the [CC BY](https://creativecommons.org/licenses/by/4.0/) license
© 2024 by the author(s)



Corresponding Author:

Sony Hidayat,

3Department of Chemistry Education, Universitas Islam Negeri Syarif Hidayatullah Jakarta, Jl. Ir. H. Juanda No. 95, Ciputat, Tangerang Selatan, Banten, Indonesia.

Email: snhdytsonyy@gmail.com

1. INTRODUCTION

Education plays a crucial role in improving the quality of human resources in the era of globalization [1], [2]. One subject that contributes to the development of scientific thinking skills is chemistry [3], [4]. However, chemistry is often considered difficult by students due to its many abstract concepts. This difficulty impacts student learning outcomes, particularly in materials requiring in-depth conceptual understanding [5], [6]. Therefore, innovation in the learning process is needed to improve student understanding and learning outcomes.

One chemistry topic that students find challenging is thermochemistry [7], [8]. Concepts in thermochemistry, such as enthalpy changes, exothermic and endothermic reactions, and Hess's law, require strong analytical skills. Many students suffer from misconceptions due to teacher-centered learning. This leads to students

tending to memorize without fully understanding the concepts [9], [10]. As a result, student learning outcomes in thermochemistry remain low.

An appropriate learning model is essential to address this issue. One such learning model is problem-based learning [11], [12]. Problem-based learning is a student-centered learning model that presents contextual problems [13], [14]. This model encourages students to think critically, solve problems, and construct knowledge independently. Thus, problem-based learning models are expected to significantly improve student learning outcomes [15], [16].

The application of problem-based learning models in chemistry has been extensively researched [17], [18]. Research results indicate that this model can improve students' critical thinking skills and conceptual understanding [19], [20]. Furthermore, problem-based learning models have also been shown to increase student engagement and motivation in learning [21], [22]. However, the implementation of problem-based learning models in thermochemistry remains suboptimal in many schools. This suggests the need for further research regarding their effectiveness in thermochemistry.

Although various studies have examined the application of problem-based learning models, there are still research gaps that require attention [23], [24]. Most studies focus more on improving critical thinking skills or learning motivation, rather than specifically on cognitive learning outcomes [25], [26]. Furthermore, research examining problem-based learning models in thermochemistry concepts is still limited and has not produced consistent results. Several studies have also not used robust experimental designs to measure significant effects. Therefore, more focused experimental research is needed to examine the effect of problem-based learning models on student learning outcomes in thermochemistry.

The novelty of this study lies in the use of an experimental design to directly test the effect of problem-based learning models on students' chemistry learning outcomes in thermochemistry concepts. This study not only assesses cognitive aspects but also considers the relationship between conceptual understanding and problem-solving processes. Furthermore, this study integrates contextual problems relevant to students' daily lives into thermochemistry learning [27], [28]. This approach is expected to provide a more meaningful learning experience. Thus, this study offers a new perspective on the application of problem-based learning models to chemistry instruction.

This research is highly urgent in efforts to improve the quality of chemistry instruction in schools. Low student learning outcomes in thermochemistry demonstrate the need for more effective learning strategies. Problem-based learning models have the potential to be a solution to address this issue. The results of this study are expected to contribute to teachers' selection of appropriate learning models. Furthermore, this study can serve as a reference for further research in developing innovative chemistry instruction. Based on this, this study aims to determine the effect of the Problem-Based Learning Model on student chemistry learning outcomes.

2. RESEARCH METHOD

2.1. Type of Research

The research method used in this study was a quasi-experimental one. The research design employed was a Nonequivalent Control Group Design or Pretest-Posttest Control Group Design, in which the experimental and control classes were not randomly selected [29]. In its implementation, the researchers involved two classes with relatively equal ability levels. The first class was designated as the experimental group receiving the treatment, while the second class served as the control group without treatment.

Before the treatment was administered, both groups took a pre-test to determine students' mastery of the material to be learned. After the learning process, both classes were given a post-test using the same instrument. The purpose of these pre-tests and post-tests was to measure changes in student learning outcomes following the treatment. The research design can be described as follows:

Table 1. Research Design

Class	Pretest	Treatment	Posttest
Experiment	E ₁	X	E ₂
Control	K ₁		K ₂

The information used in this study includes the symbol E, which indicates the results of the initial and final tests in the experimental class, and the symbol K, which indicates the results of the initial and final tests in the control class. The symbol X is used to indicate the treatment given to students during the learning process. Based on the research design, both classes, both the experimental and control classes, were first given a pre-test before the treatment was carried out. This pre-test aims to determine students' initial abilities regarding the material to be studied. Next, in the learning stage, the experimental class was given treatment in the form of the application of a problem-based learning model. Meanwhile, the control class followed learning with conventional methods, such as discussion and question and answer. In the final stage, both classes were given a post-test to measure

students' abilities after the learning process took place. This post-test was used to determine the differences in student learning outcomes between the class that was given the treatment and the class that was not given the treatment.

2.2. Population and Sample

The target population in this study was all students at State Senior High School 3 in South Tangerang City. Meanwhile, the accessible population in this study was all eleventh-grade students at the school during the same academic year. Determining the accessible population was done to ensure the research was more focused and aligned with the desired objectives.

Sampling was conducted using a non-probability sampling technique, a technique that does not provide an equal opportunity for every member of the population to be selected as a sample [30]. The method used was purposive sampling, which determines the sample based on specific considerations relevant to the research objectives. In this study, the eleventh-sixth grade students were selected as the experimental class, which used a problem-based learning model in its learning process. Meanwhile, the eleventh-seventh grade students were designated as the control class, which used conventional learning.

2.3. Data Collection Techniques

The research instrument used to collect data for this study was a test. The test consisted of 20 multiple-choice questions, each with five alternatives. Students who answered correctly on each question were given a score of 1, while students who answered incorrectly were given a score of 0. The instrument framework used in this study is as follows:

Table 2. Instrument Grid

Concept	Indicator	Item Number			Amount
		C1	C2	C3	
Types of enthalpy changes	<ul style="list-style-type: none"> Explain the standard enthalpy of formation Explain the standard enthalpy of decomposition Explain the standard enthalpy of combustion 	7,15,30,40			4
Application of reaction heat calculations	Determining the ΔH value of a reaction based on simple experimental data			24,6,18	3
Hess's law and standard enthalpy of formation data	Determine the ΔH value of a reaction using Hess's law	16	4,3,9	23	5
Determine the ΔH value of a reaction using standard enthalpy change data for formation.	Calculating ΔH of a reaction based on standard enthalpy of formation data		28	33	2
Determining ΔH of a reaction using bond energy data	Calculating the ΔH value of a reaction using bond energy data		11,8	37	3
Impact of fuel combustion	Explaining incomplete combustion of fuel	27,22	35		3
Amount		7	7	6	20

2.4. Data Analysis Techniques

2.4.1. Testing Analysis Prerequisites

A data normality test is performed to determine whether the sample data used in the study is normally distributed. In this study, the Liliefors test was used because its calculation is relatively simple and maintains good reliability despite the small sample size [31]. The test was conducted at a significance level of 0.05. The steps of the Liliefors test are as follows. First, the observed data are converted to standard values using the sample mean and standard deviation. Second, for each standard value, the cumulative probability is calculated based on the standard normal distribution. Third, the proportion of data less than or equal to a certain value is determined. Next, the difference between the theoretical probability and the empirical proportion is calculated in absolute value. The largest of these differences is then designated as the test statistic.

A homogeneity test is performed to determine whether the data originate from populations with equal variances. This equality of variances is one of the requirements for using parametric statistical tests. In this study, the homogeneity test was performed using the Fisher exact test. The Fisher exact test begins with formulating hypotheses: the null hypothesis stating that the variances of the two groups are equal, and the alternative hypothesis stating that the variances of the two groups are unequal [32]. Next, the data was divided into two groups, and the

standard deviation for each group was calculated. The test statistic value was obtained by comparing the largest variance with the smallest variance. After that, the significance level and degrees of freedom for the numerator and denominator were determined. The test criteria were: if the test statistic value is less than or equal to the value in the table, then the variances of the two groups are considered homogeneous; if it is greater than or equal to the value in the table, then the variances are considered heterogeneous.

2.4.2. Hypothesis Testing

Hypothesis testing in this study was conducted using a t-test at a significance level of 0.05. This test aims to determine whether there is a significant difference between the learning outcomes of the experimental and control groups. In calculating the t-test, the average value of each group, namely the experimental group and the control group, was used [33]. In addition, the combined standard deviation value obtained from both groups was also used. The number of data in each group and the variance of each group were also taken into account in this analysis. The calculation results were then compared with the values in the table to determine whether the null hypothesis was accepted or rejected.

3. RESULTS AND DISCUSSION

3.1. Testing Analysis Prerequisites

Before conducting a hypothesis test using the t-test to see the influence of the given behavior, it is necessary to test the analysis prerequisites using parametric analysis as follows:

3.1.1. Normality Test

The normality test was conducted to determine whether the sample studied was normally distributed or not in this study, so the normality test used was the Liliefors test. The acceptance criteria for whether the data was normally distributed or not were formulated as follows: If $L_{hitung} < L_{tabel}$ means the data is normally distributed. If $L_{hitung} > L_{tabel}$ means the data is not normally distributed. After data processing, the pretest normality for the experimental class and the control class was obtained as follows:

Table 3. Results of the Normality Test for Pretest Score Data

No.	Statistics	Experimental Class	Control Class
1.	N	30	30
2.	\bar{x}	24.17	21.00
3.	Standard Deviation	11.82	9.14
4.	L_{count}	0.152	0.152
5.	L_{Table}	0.161	0.161
Conclusion		Normal	Normal

Based on the data in table 4.3, the L_{count} of the pretest score of the experimental class students was 0.152 and L_{table} ($n = 30$) was 0.161; which shows that the experimental class data is normally distributed, because it meets the criteria of $L_{count} < L_{table}$ ($0.152 < 0.161$). Meanwhile, for the control class, the L_{count} was 0.152 with L_{table} ($n = 30$) of 0.161; which shows that the control class data is also normally distributed, because it meets the criteria of $L_{count} < L_{table}$ ($0.152 < 0.161$). Thus, both research samples on the pretest scores of the experimental class and the control class meet the criteria, the null hypothesis is accepted and means the data is normally distributed.

After data processing, the post-test normality for the experimental class and control class was obtained as follows:

Table 4. Results of the Normality Test for Posttest Score Data

No.	Statistics	Experimental Class	Control Class
1.	N	30	30
2.	\bar{x}	70.17	63.33
3.	Standard Deviation	10.95	12.27
4.	L_{count}	0.114	0.118
5.	L_{Table}	0.161	0.161
Conclusion		Normal	Normal

Based on the data in table , the L_{count} posttest score of the experimental class students was 0.114 and L_{table} ($n = 30$) was 0.161; which shows that the experimental class data is normally distributed, because it meets the criteria of $L_{count} < L_{table}$ ($0.110 < 0.161$). Meanwhile, for the control class, the L_{count} was 0.118 with L_{table} ($n = 30$) of 0.161; which shows that the control class data is also normally distributed, because it meets the criteria of

$L_{\text{count}} < L_{\text{table}}$ ($0.118 < 0.161$). Thus, both research samples on the posttest scores of the experimental class and the control class meet the criteria for the null hypothesis to be accepted, which means the data is normally distributed.

3.1.2. Homogeneity Test

After both classes of research samples are declared normally distributed, the next step is to find the homogeneity value of the two research classes. After both research samples are declared normally distributed, the next step is to find the homogeneity value using the Fisher exact test. The test criteria used are if $F_{\text{count}} < F_{\text{table}}$ then H_0 is accepted, meaning both data are homogeneous and if $F_{\text{count}} > F_{\text{table}}$ then H_0 is rejected, meaning both data are not homogeneous. After data processing, the pretest homogeneity test for the experimental class and the control class is as follows:

Table 5. Results of the Pretest Score Homogeneity Test

	Statistical Data
N Experiment	30
N Control	30
S_{big}^2	$(11.82)^2$
S_{small}^2	$(9.14)^2$
F_{count}	1.67
F_{table}	1.85
Conclusion	Homogen

Based on table 5, the F_{count} was 1.67 with $n = 60$ at a confidence level of 5% ($\alpha = 0.05$) and the F_{table} was 1.85. Therefore, both research classes were declared homogeneous because they met the criteria of $F_{\text{count}} < F_{\text{table}}$ ($1.67 < 1.85$). After data processing, the posttest homogeneity test for the experimental class and the control class was as follows:

Table 6. Results of the Posttest Score Homogeneity Test

	Statistical Data
N Experiment	30
N Control	30
S_{big}^2	$(12.27)^2$
S_{small}^2	$(10.95)^2$
F_{count}	1.26
F_{table}	1.85
Conclusion	Homogen

Based on table 6, the F_{count} was 1.26 with $n = 60$ at a confidence level of 5% ($\alpha = 0.05$) and the F_{table} was 1.85. Therefore, both research groups were declared homogeneous because they met the criteria of $F_{\text{count}} < F_{\text{table}}$ ($1.26 < 1.85$).

3.2. Hypothesis Testing

This hypothesis testing was conducted after conducting normality and homogeneity tests. This hypothesis testing used the t-test (t-test), to test the null hypothesis (H_0) which states that there is no effect of the Problem Based Learning learning model on students' chemistry learning outcomes. The criteria for the t-test conclusion results are as follows: if $t_{\text{count}} < t_{\text{table}}$ then H_0 is accepted and H_a is rejected, whereas if $t_{\text{count}} > t_{\text{table}}$ then H_0 is rejected and H_a is accepted.

Table 7. t-Test of Student Learning Outcomes Pre-test Score

Variables	Number of Samples	t_{count}	t_{table}	Conclusion
Student learning outcomes	$n_1 = 30$ dan $n_2 = 30$	0.29	2.048	Accept H_0 and Reject H_a

Based on the data in table 7, the calculation results of t count are 0.29 with t table at a significance level of $\alpha = 0.05$ and degrees of freedom ($df/db = 30+30-2 = 58$) is 2.048. So it can be concluded that $t_{\text{count}} < t_{\text{table}}$ ($0.29 < 2.048$) so that the null hypothesis (H_0) is accepted and the alternative hypothesis (H_a) is rejected. Thus it can be concluded that there is no difference between the pretest of the experimental class and the pretest of the control class.

Table 8. t-Test of Student Learning Outcomes Posttest Score

Variables	Number of Samples	t_{count}	t_{table}	Conclusion
Student learning outcomes	$n_1 = 30$ dan $n_2 = 30$	2.228	2.048	Accept H_0 and Reject H_a

Based on the data in Table 8, the calculated t-value is 2.228, with a t-value at a significance level of $\alpha = 0.05$ and a 2.048 degrees of freedom ($df/db = 30 + 30 - 2 = 58$). Therefore, it can be concluded that t-value > t-value (2.228 > 2.048), thus rejecting the null hypothesis (H_0) and accepting the alternative hypothesis (H_a). Therefore, this hypothesis can be tested, namely, that the problem-based learning model has a significant influence on learning outcomes.

The results of this study indicate that the application of the problem-based learning model has a positive impact on the chemistry learning process, particularly on thermochemistry concepts. This can be explained because the problem-based learning model places students at the center of learning, allowing them to be more active in constructing their own knowledge. This active involvement allows students to connect abstract concepts with real-world situations, making them easier to understand. Furthermore, the gradual problem-solving process helps students develop a deeper conceptual understanding. Thus, learning is not merely rote but also emphasizes conceptual meaning.

The advantage of the problem-based learning model also lies in its ability to develop higher-order thinking skills. In thermochemistry, students are not only asked to understand concepts but also to analyze and solve problems related to energy changes in chemical reactions [34]. This activity encourages students to develop critical and logical thinking skills. Furthermore, the group discussions that are part of this model allow for the exchange of ideas among students. This interaction contributes to enriching understanding and correcting potential misconceptions.

In contrast, conventional learning tends to be teacher-centered and provides few opportunities for students to explore knowledge independently. Methods such as lectures and question-and-answer sessions often emphasize only the delivery of information without actively engaging students in the thinking process [35]. As a result, students more easily struggle to grasp abstract concepts like thermochemistry. This lack of engagement also impacts students' ability to apply concepts to new situations. Therefore, a more interactive and contextual learning approach is needed.

The findings of this study align with constructivism theory, which states that knowledge is actively constructed by individuals through learning experiences. The problem-based learning model provides space for students to construct their knowledge through inquiry and problem-solving [36]. By exposing students to challenging situations, they are encouraged to seek solutions independently and collaboratively. This process not only improves conceptual understanding but also fosters more independent learning skills. This is crucial in chemistry learning, which demands a strong conceptual understanding.

Furthermore, the use of contextual problems in thermochemistry learning provides a more meaningful learning experience for students. Problems raised from everyday life help students understand the relevance of the material being studied. This can increase learning motivation because students feel that the learning is directly related to their lives. Increased motivation will impact student engagement in the learning process [37], [38]. Thus, learning becomes more effective and oriented towards long-term understanding.

The implications of this study suggest that teachers need to consider using innovative learning models in teaching chemistry. The problem-based learning model can be an effective alternative to improve the quality of learning [39], [40]. However, implementing this model requires careful planning, particularly in formulating problems appropriate to the students' ability levels. Furthermore, teachers need to act as facilitators, guiding the learning process. With the right support, this model can deliver optimal results in improving student learning outcomes.

However, there are several limitations to this study that should be considered. One is the limited scope of the material, which focused solely on thermochemistry concepts. Furthermore, other factors such as learning motivation, students' prior abilities, and the learning environment can also influence learning outcomes. Therefore, further research is recommended to examine other variables that can strengthen these findings. This way, the development of problem-based learning models can be carried out in a more comprehensive and sustainable manner.

4. CONCLUSION

Based on the results of the research and data analysis that have been described in the previous chapter, it can be concluded that the learning outcome test in the experimental class obtained a mean posttest score of 70.17 and in the control class the mean posttest score was 63.33. From these results it is proven that the learning outcome scores of students taught using the Problem Based Learning learning model are higher than students taught using the conventional learning model. The results of the posttest hypothesis calculation using the t-test at a significance level of 0.05 are obtained $t_{count} > t_{table}$, namely $2.228 > 2.048$. From these results it can be concluded that the hypothesis test rejects the null hypothesis (H_0) and accepts the alternative hypothesis (H_a). And the results of this calculation prove that learning using the Problem Based Learning learning model has a significant influence on learning outcomes.

ACKNOWLEDGEMENTS

The author would like to thank all parties who supported this research, especially the schools, teachers, and students who actively participated. He also thanks his colleagues who provided input and assistance throughout the research process and the preparation of this article. He hopes their contributions will be well-received.

AUTHOR CONTRIBUTIONS

S. H. and O. A. J. contributed to conceptualization and validation; S. H. handled methodology, software, formal analysis, investigation, data curation, original draft, and visualization; O. A. J. managed resources, review & editing, supervision, project administration, and funding acquisition.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

REFERENCES

- [1] T. Sumual, H. Lumapow, and V. Rotty, "The role of human capital investment in improving the quality of human resources (HR) in education in the digital era," *Asian J. Eng. Soc. Heal.*, vol. 3, no. 11, pp. 2520–2528, 2024, doi: 10.46799/ajesh.v3i11.449.
- [2] S. Arifin, M. Isa Ansori, and H. Buyung Aulia Safrizal, "Human resources in the era of globalization employee challenges in improving the quality of human resources in the era of globalization," *J. Ilm. Manaj. Kesatuan*, vol. 11, no. 3, pp. 1457–1466, 2023, doi: <https://jurnal.ibik.ac.id/index.php/jimkes/article/view/2286>.
- [3] B. Al-Ajmi and A. Ambusaidi, "The level of scientific argumentation skills in chemistry subject among grade 11th students: The role of logical thinking," *Sci. Educ. Int.*, vol. 33, no. 1, pp. 66–74, 2022, doi: 10.33828/sci.v33.i1.7.
- [4] M. Jamil, T. B. Bokhari, and Q. Zia, "Qualitative content analysis for critical thinking and skill development: A case of chemistry curriculum," *J. Asian Dev. Stud.*, vol. 13, no. 1, pp. 147–155, Feb. 2024, doi: 10.62345/jads.2024.13.1.12.
- [5] R. Laelandi, A. Widodo, and S. Sriyati, "Depth of science learning materials in schools and student concept mastery," *J. Penelit. Pendidik. IPA*, vol. 8, no. 3, pp. 1470–1478, 2022, doi: 10.29303/jppipa.v8i3.1706.
- [6] S. Rahmah and A. H. Lubis, "Problem posing as a learning model to improve primary school students' mathematics learning outcomes in gayo lues," *J. Indones. Prim. Sch.*, vol. 1, no. 4, pp. 93–104, 2024.
- [7] R. R. T. Agustina, A. Afadil, S. Rahmawati, and V. M. A. Tiwow, "Learning difficulties and students' ability level during pandemic covid-19 on the subject of thermochemistry," *J. Akad. Kim.*, vol. 12, no. 1, pp. 26–31, 2023, doi: 10.22487/j24775185.2023.v12.i1.pp26-31.
- [8] M. A. Barus and J. Purba, "Development of problem-based integrated student worksheets (LKPD) in thermochemistry class XI high school," *J. Multidisiplin Indones.*, vol. 4, no. 3, pp. 212–229, 2025, doi: 10.58344/jmi.v4i3.2244.
- [9] D. T. K. Ng, C. Xinyu, J. K. L. Leung, and S. K. W. Chu, "Fostering students' AI literacy development through educational games: AI knowledge, affective and cognitive engagement," *J. Comput. Assist. Learn.*, vol. 40, no. 5, pp. 2049–2064, 2024, doi: 10.1111/jcal.13009.
- [10] E. Byusa, E. Kampire, and A. R. Mwesigye, "Game-based learning approach on students' motivation and understanding of chemistry concepts: A systematic review of literature," *Heliyon*, vol. 8, no. 5, p. e09541, 2022, doi: 10.1016/j.heliyon.2022.e09541.
- [11] A. Suradika, H. I. Dewi, and M. I. Nasution, "Project-based learning and problem-based learning models in critical and creative students," *J. Pendidik. IPA Indones.*, vol. 12, no. 1, pp. 153–167, 2023, doi: 10.15294/jpii.v12i1.39713.
- [12] K. Smith *et al.*, "Principles of problem-based learning (PBL) in STEM education: Using expert wisdom and research to frame educational practice," *Educ. Sci.*, vol. 12, no. 10, pp. 1–20, 2022, doi: 10.3390/educsci12100728.
- [13] M. S. J. Maftuh, U. S. Lawal, M. Ade, A. V. Lama, and A. F. Adzim, "Understanding learning strategies: A comparison between contextual learning and problem-based learning," *Educ. J. Educ. Learn.*, vol. 01, no. 01, pp. 54–65, 2023, doi: 10.61987/educazione.v1i1.496 Understanding.
- [14] M. Mahrusillah and M. A. Ahmad, "Contextual learning strategy : Theoretical analysis and implementation of student-centered learning," *J. Pendidik. dan Pemikir. Islam eISSN*, vol. 5, no. 2, pp. 513–534, 2025, doi: 10.31869/ruhama.v4i1.2605.1.
- [15] A. Abdurahman, A. Asfahani, N. Sudarwati, F. Warwer, and A. Asrijal, "The influence of problem-based learning model on students' learning outcomes," *AIP Conf. Proc.*, vol. 2733, no. 1, pp. 247–255, 2023, doi: 10.1063/5.0140515.
- [16] N. F. Aristin, K. P. Hastuti, D. Arisanty, S. Adyatma, and C. Donna, "Effectiveness of problem-based learning models to improve learning outcomes of geography in the new normal learning era," *J. Educ. Learn.*, vol. 17, no. 4, pp. 623–632, Nov. 2023, doi: 10.11591/edulearn.v17i4.20834.
- [17] I. Arifiani, L. NurulH, and S. Rahmawan, "Problem based learning (PBL) learning model for increasing learning motivation in chemistry subject: Literature review with bibliometric analysis," *ASEAN J. Sci. Educ.*, vol. 4, no. 1, pp. 17–30, 2025, doi: <https://www.ejournal.bumipublikasinusantara.id/index.php/ajsed/article/view/523>.
- [18] D. Wahyudiati, "Critical thinking skills and scientific attitudes of Pre-service chemistry teachers through the implementation of problem-based learning model," *J. Penelit. Pendidik. IPA*, vol. 8, no. 1, pp. 216–221, 2022, doi: 10.29303/jppipa.v8i1.1278.

- [19] M. A. P. Nugraha, J. S. V. Sinolungan, R. Nur, S. Nuridah, N. Nofirman, and D. Cahyono, "Conceptual analysis of problem-based learning model in improving students critical thinking skill," *J. Educ. Res.*, vol. 4, no. 2, pp. 466–473, 2023, doi: 10.37985/jer.v4i2.185.
- [20] B. J. Que, I. H. Kusnadi, R. M. P. Silalahi, A. A. Rahman, and A. Kurniawan, "The effect of deep dialogue/critical thinking model on students' conceptual understanding ability," *J. Innov. Educ. Cult. Res.*, vol. 3, no. 3, pp. 422–431, 2022, doi: 10.46843/jiecr.v3i3.130.
- [21] M. Arsyad, S. Guna, and S. Barus, "Enhancing chemistry education through problem-based learning: Analyzing student engagement, motivation, and critical thinking," *Int. J. Curric. Dev. Teach. Learn. Innov.*, vol. 2, no. 3, pp. 110–117, Jul. 2024, doi: 10.35335/curriculum.v2i3.178.
- [22] R. Safitri, S. Hadi, and W. Widiasih, "Effect of the problem based learning model on the students motivation and learning outcomes," *J. Penelit. Pendidik. IPA*, vol. 9, no. 9, pp. 7310–7316, 2023, doi: 10.29303/jppipa.v9i9.4772.
- [23] G. Nicholus, C. M. Muwonge, and N. Joseph, "The role of problem-based learning approach in teaching and learning physics: A systematic literature review," *F1000Research*, vol. 12, pp. 1–23, 2023, doi: 10.12688/f1000research.136339.2.
- [24] Q. Zhuo, D. Wang, H. Xu, W. Liu, and L. Gao, "Pore structure and permeability of filter cake in coal slurry filtration," *Int. J. Coal Prep. Util.*, vol. 42, no. 2, pp. 155–170, Feb. 2022, doi: 10.1080/19392699.2019.1585830.
- [25] R. Rafia, A. Maulidiyah, H. Haeruddin, and M. Jamhari, "The effect of critical thinking ability and learning motivation on IPAS learning outcomes," *J. Reviu Pendidik. Dasar J. Kaji. Pendidik. dan Has. Penelit.*, vol. 11, no. 1, pp. 12–22, 2025, doi: 10.26740/jrpd.v11n1.p12-22.
- [26] H. K. Indriyani, D. Purwaningsih, and W. Khaokhajorn, "The effects of problem-based learning on critical thinking, motivation, and learning outcomes in Indonesia: A systematic review," *J. Pendidik. MIPA*, vol. 12, no. 1, pp. 1–7, 2022, doi: 10.23960/jpmipa.v26i3.pp1750-1777.
- [27] D. Y. Asiamah, J. Ekow, M. Amoah, K. A. Hayford, and E. K. Dorman, "Exploring alternative conceptions and learning challenges in thermochemistry: Evidence from Ghanaian SHS students," *Eur. J. Basic Appl. Sci.*, vol. 12, no. 1, pp. 1–14, 2025, doi: 10.5281/zenodo.17217282.
- [28] D. M. Condong *et al.*, "STEM-integrated problem-based learning as a cognitively aligned framework for enhancing critical thinking in thermochemistry," *Jambura J. Educ. Chem.*, vol. 8, no. 1, pp. 120–128, 2026.
- [29] C. K. Assuah, G. K. Mantey, and L. Osei, "The effect of think-pair-share learning on junior high school students' achievement in algebraic expressions: Pre-test-post-test non-equivalent control group design," *Asian J. Probab. Stat.*, vol. 20, no. 2, pp. 46–55, 2022, doi: 10.9734/ajpas/2022/v20i2418.
- [30] B. H. Mukti, "Methods in health research: Probability and non-probability sampling," *Heal. Sci. Int. J.*, vol. 3, no. 2, pp. 220–234, 2025, doi: 10.71357/hsj.v3i2.64.
- [31] L. Vankelecom, T. Loeyls, and B. Moerkerke, "How to safely reassess variability and adapt sample size? A primer for the independent samples t test," *Adv. Methods Pract. Psychol. Sci.*, vol. 7, no. 1, pp. 1–20, 2024, doi: 10.1177/25152459231212128.
- [32] S. Sundararajan, "Hypothesis Testing," 2025, pp. 113–141. doi: 10.1007/978-981-99-0353-5_4.
- [33] A. Triyono, R. H. Nuary, N. Permatasari, Y. Yuni, and T. Wibowo, "The level of effectiveness of TPS and conventional methods judging from students' geometry learning results using the N-Gain test," *AlphaMath J. Math. Educ.*, vol. 10, no. 1, p. 125, 2024, doi: 10.30595/alphamath.v10i1.21530.
- [34] C. Stroumpouli and G. Tsaparlis, "Chemistry students' conceptual difficulties and problem solving behavior in chemical kinetics, as a component of an introductory physical chemistry course," *Chem. Teach. Int.*, vol. 4, no. 3, pp. 279–296, 2022, doi: 10.1515/cti-2022-0005.
- [35] P. Karuru, Muta'allim, Suparjo, A. F. Setiawan, and S. Junaida, "Improving students' higher order thinking skills through a question and answer method," *RETORIKA J. Ilmu Bhs.*, vol. 9, no. 3, pp. 340–349, 2023, doi: <https://ejournal.warmadewa.ac.id/index.php/jret>.
- [36] M. Hala, A. Prof, and N. Xhomara, "The impact of inquiry-based learning on problem-solving skills and conceptual knowledge building," *Psychol. Educ.*, vol. 59, no. 2, pp. 909–921, 2022, [Online]. Available: www.psychologyandeducation.net
- [37] J. Zajda, "The Impact of Motivation on Students' Engagement and Performance," 2023, pp. 127–138. doi: 10.1007/978-3-031-42895-1_9.
- [38] K. Al-Said, "Influence of teacher on student motivation: Opportunities to increase motivational factors during mobile learning," *Educ. Inf. Technol.*, vol. 28, no. 10, pp. 13439–13457, 2023, doi: 10.1007/s10639-023-11720-w.
- [39] I. Apriyanti, Leginem, and S. Rahayu, "Efforts to Improve Student Learning Outcomes through the Problem Based Learning Model in Islamic Education Learning at SD Negeri 104325 Kampung Manggis," *J. Indones. Prim. Sch.*, vol. 1, no. 2, pp. 61–68, Jun. 2024, doi: 10.62945/jips.v1i2.346.
- [40] A. Islamiati, Y. Fitria, E. Sukma, Yaswinda, E. Fitria, and S. T. Oktari, "The influence of the problem based learning (PBL) model and learning style on the thinking abilities," *J. Penelit. Pendidik. IPA*, vol. 10, no. 4, pp. 1934–1940, 2024, doi: 10.29303/jppipa.v10i4.6219.