Journal of Educational Sciences
Journal homepage: https://jes.ejournal.unri.ac.id/index.php/JES

P-ISSN 2581-1657
E-ISSN 2581-2203

The Implementation of STEM-Integrated Project-Based Learning (Pjbl) to Improve Students' Critical Thinking Skills

Tania Avianda Gusman, Sodikin*, Mutiara Dwi Cahyani
Chemistry Education, University of Muhammadiyah Cirebon, Cirebon, 45611, Indonesia

ARTICLE INFO

Article history:

Received: 02 Nov 2025
Revised: 14 Des 2025
Accepted: 23 Des 2025
Published online: 05 Jan 2026

Keywords:

Project-based Learning,
STEM,
Critical Thinking Skills,
Thermochemistry

* *Corresponding author:*

E-mail: ikinsodik091@gmail.com

Article Doi:

https://doi.org/10.31258/jes.10.1.p.71-84

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A B S T R A C T

This study addresses the low level of students' critical thinking skills in chemistry learning, particularly in the context of thermochemistry, which is an abstract and complex concept to visualize. To overcome this challenge, Project-Based Learning (PBL) was integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach. The research aimed to examine the improvement of students' critical thinking skills and to explore their responses toward the PjBL-STEM model. A quantitative experimental method was employed with purposive sampling of 11th-grade senior high school students. Research instruments included a critical thinking test based on Facione's indicators, observation sheets, and student response questionnaires. The data were analyzed using both descriptive and inferential statistical techniques. The findings revealed a significant improvement, with the average score increasing from 47% in the pre-test to 74% in the post-test. Students showed better performance in interpretation, analysis, evaluation, inference, explanation, and self-regulation. Furthermore, responses toward the PjBL-STEM model were highly positive, with 67% of students agreeing and 21% strongly agreeing with its implementation. These results suggest that PjBL-STEM provides a practical, interactive, and contextual learning experience, thereby enhancing students' critical thinking skills in chemistry education.

1. Introduction

Chemistry is one of the branches of natural sciences that studies matter, including its properties, structure, composition, and the changes it undergoes along with the energy involved in those changes (Lumadyah, 2024). Understanding basic chemical concepts is a crucial foundation for comprehending natural phenomena, chemical reactions, and interactions between substances. Without a solid grasp of these concepts, students often struggle to connect theory with practice, which can make

chemistry learning appear abstract and uninteresting. In the context of formal education, learning is a systematic process aimed at developing students' potential through the transfer of knowledge, skills, values, and norms. The National Education System Law No. 20 of 2003 emphasizes that education serves to develop abilities and shape the character, as well as the civilization, of a dignified nation. One of the challenges of 21st-century education is preparing a generation that is creative, critical, innovative, and adaptive to technological advancements. Therefore, teachers are required to select learning models that are relevant to the characteristics of students and the subject matter being taught (Faiz, 2022). In implementing a learning model in the classroom, teachers must have an understanding of the students' conditions, the available facilities and infrastructure, as well as various other factors (Gusman, 2025).

One of the chemistry topics that requires a high level of critical thinking skills is thermochemistry. This topic discusses the relationship between chemical reactions and energy changes, including concepts of enthalpy, exothermic reactions, and endothermic reactions. Due to its abstract nature and the need for mastery of mathematical concepts, many students struggle to understand this material (Johan, 2024). Previous studies have shown that low learning outcomes in thermochemistry are often caused by the lack of learning models that facilitate active student engagement and the development of critical thinking skills (Salbiah, 2017). One approach considered effective in addressing this problem is Project Based Learning (PjBL). The PjBL model positions students as the subjects of learning, where they are directly involved in designing, implementing, and completing a project to produce a real product (Nababan, 2023). PjBL not only enhances conceptual understanding but also sharpens critical, creative, collaborative, and communicative skills. In chemistry learning, PjBL provides opportunities for students to solve contextual problems that are relevant to everyday life (Rona Taula Sari, 2018).

The rapid development of technology and information requires education today to actively utilize technology as an innovation in the learning process. Technology integrated into learning is one of the strategies to achieve learning objectives (Cahyani, 2023). One of the learning models that can be developed to enhance critical thinking skills is the STEM-based learning model (Gusman, 2023).To be more relevant to the demands of the 21st century, Project Based Learning (PjBL) can be integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach. This integration focuses learning on connecting scientific concepts with technology, engineering, and mathematics, enabling students to gain a holistic understanding and applicable problem-solving skills (Barkah, 2024). The PjBL-STEM learning model has been proven to increase learning motivation, develop collaborative skills, and strengthen the connection between theoretical concepts and their real-life applications (Ralph, 2015; Mamahit et al., 2020). This approach is also aligned with the principles of the Merdeka Curriculum, which emphasizes contextual and project-based learning.

Critical thinking skills are one of the core competencies that need to be developed through 21st-century learning. Twenty-first century learning presents a significant challenge in today's educational landscape, thus requiring high-quality human resources to meet the demands of the 21st century (Gusman, 2023). Ennis (2000) classifies critical thinking skills into three main aspects: (1) Elementary clarification the ability to clearly explain problems, (2) The basis for decision the ability to provide logical reasons in decision-making, and (3) Inference the ability to draw valid conclusions. The PjBL-STEM model naturally encourages students to go through these processes, starting from identifying problems, designing solutions, testing hypotheses, and drawing conclusions from experimental results.

Unfortunately, observations and several studies indicate that the implementation of the PjBL-STEM model in schools, particularly in thermochemistry, remains limited. Teachers tend to rely on lectures or simple laboratory activities, which do not fully facilitate students' active engagement (Wijaya et al., 2018; Khoirunnisa, 2020). On the other hand, students' responses toward project-based learning integrated with STEM have not been extensively explored in the context of chemistry education in Indonesia. This gap underlines the importance of conducting research on the implementation of the PjBL-STEM learning model to enhance students' critical thinking skills in thermochemistry. This study is expected to contribute to the development of more innovative chemistry learning strategies that are relevant to 21st-century demands and aligned with the principles of contextual learning in the Merdeka Curriculum.

2. Methodology

This research employed a quantitative approach with a quasi-experimental method using a non-equivalent control group design. The subjects were eleventh-grade science students at SMA Negeri 1 Sindangwangi, consisting of two classes: an experimental class that received instruction through the Project Based Learning (PjBL) model integrated with STEM implemented by engaging students in problem-solving activities related to current env ironmental issues and a control class that received conventional instruction. The research instrument was a critical thingking skills test in the form of essay question, developed based on Facione's (2015) indicators, which include interpretation, analysis, evaluation, inference, and explanation, the test was validated by experts and piloted to determine its validity, reliability, difficulty level, and discrimination index. Data collection was conducted through pre-test and post-test administered to both classes. The data were analyzed using normality tests, homogeneity tests, and independent t-test to determine differences in critical thinking skills between the two groups. The following researcher presents the flow of this research which can be seen in figure 1.

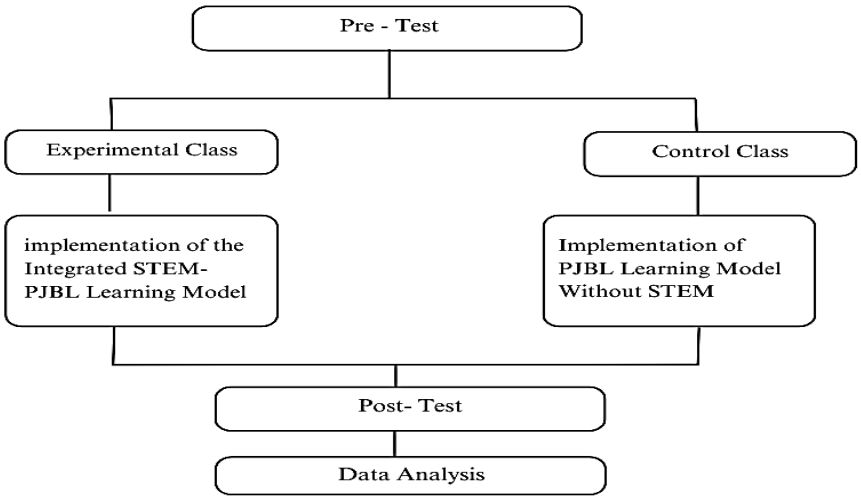

Figure 1. Research Flow

To measure the improvement of students' critical thinking skills, the researcher also collected data regarding students' responses using a response questionnaire with a Likert scale. According to Sugiyono (2019), a questionnaire is an indirect method of data collection consisting of a set of statements or questions to be answered by respondents. This response questionnaire was administered to students at the end of the learning process to determine their perceptions of learning through the STEM approach. The questionnaire in this study consisted of 17 statements, including 15 positive and 2 negative items (Ramdan, 2022).

3. Results and Discussion

In implementing learning, it is necessary to measure the results of the STEM-integrated PjBL model to determine whether the implementation has been effective. Therefore, researchers used observation instruments to assess the implementation of the learning process, with the results presented in table 1.

Table 1. Observation Results of the Implementation of PjBL-STEM

No	Activities	Skor	Skor Max	Presentase
1	Introduction	20	24	83%
2	Main Body	33	36	91%
3	Conclusion	10	12	83%
		63	72	86%

Besed on observations made during the implementation of STEM integrated Project-Besed Learning (PjBL), the learning achievement rate reached 86%. This indicates that the implementation of the STEM integrated Project- Based Learning (PjBL) model conducted by the researcher has been effective. To measure the improvement of students' critical thingking skills, the researcher used pre-test and post-test instruments. The results of the analysis were conducted after the

prerequisite of students' critical thingking skill, the researcher used pre-test and post-test instruments. The results of the analysis were conducted after the prerequisite test using SPSS 27, with the findings presented in table 2.

Table 2. Pre-Test and Post-Test Results of the Experimental and Control Classes

	N	Minimum	Maximum	Mean	Std. Deviation
Pre-Test Experiment	35	30	62	47.23	8.875
Post-Test Experiment	35	50	92	73.71	11.245
Pre-Test Control	35	30	62	47.23	9.039
Post-Test Control	35	40	80	60.40	10.950
Valid N (listwise)	35				

In the experimental class, the pre-test data showed an average score of 47, while the post-test average increased to 74. This indicates a significant variation between the mean scores. In the pre-test, the highest score obtained by students was 62 and the lowest was 30. In the post-test, the highest score reached 92 and the lowest was 50. These results demonstreate a notable difference between the lowest and highest scores, as the data cover a wide range. To better illustrate the comparison of average scores between the the experimental and control classes, the researcher presents a bar chart in figure 2.

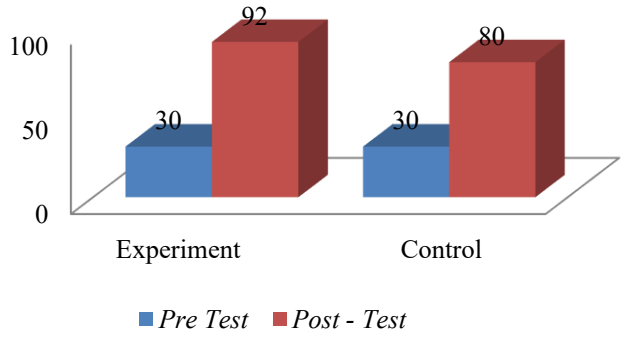

Figure 2. Comparison of Pre-test and Post-test Average Scores in the Experimental and Control Classes

The critical thinking ability scores of students in the experimental and control classes showed no significant difference in the pre-test, as illustrated in Figure 4.1. The pre-test score in the experimental class was 30. However, differences were observed in the post-test results. In the experimental class, the highest post-test score was 92, while in the control class it was 80, with an average difference of 12. Thus, it can be concluded that students in the experimental class demonstrated better critical thinking skills compared to those in the control class. Although the difference was not subtantial, this indicates a positive change following the application of the Project Based Learning (PjBL) model integrated with STEM in the experimental class.

This finding is consistent with research conducted by Leni Rosilawati (2025), who reviewed 10 articles and found similatiries in the conclusion that STEM-based

learning can improve students' critical thinking skills. Critical thinking is part of higher-order thinking skill (HOTS), which represent an essential competency that students' critical thinking skills, the researcher analyzed each indicator of critical thinking skills to determine the extent of improvement after the implementation of the PjBL-STEM learning model. The results of the analysis of critical thinking indicators in the experimental class are presented in figure 3.

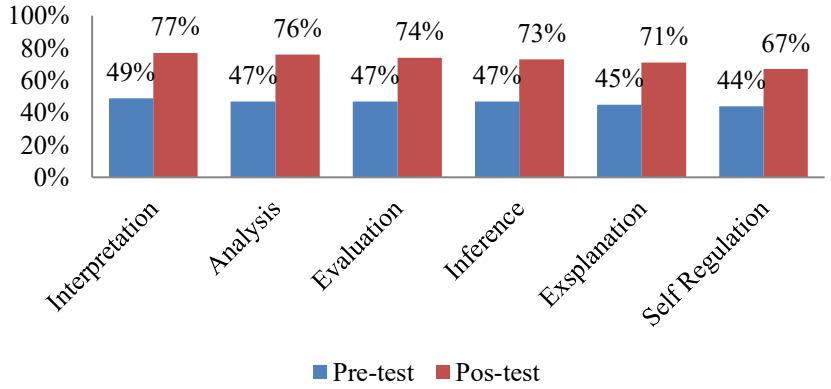

Figure 3. Improving Critical Thingking in Each Indicator

Based on Table 4.8, it can be seen that the implementation of the Project-Based Learning (PBL) model integrated with STEM in thermochemistry lessons was able to improve students' critical thinking skills in the experimental class for each indicator. In the pre-test, students' skills were still categorized as low, while in the post-test, they improved to the medium and good categories. At the end of the learning process in the experimental class, the researcher distributed a questionnaire to students to identify the strengths and weaknesses of the learning implementation and to facilitate evaluation for future lessons. In this study, the questionnaire consisted of 17 statements with a four-point Likert scale. The results of the questionnaire can be seen in Figure 4.

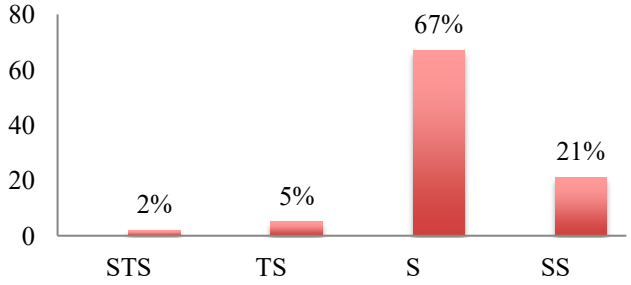

Figure 4. Student Response Results

The analysis of the questionnaire results showed that no students gave negative responses toward the implementation of the Project Based Learning (PjBL) model integrated with STEM in thermochemistry lessons. This indicates that the application of this learning model was well received by students and was able to provide them with engaging experiences through the projects conducted. The

analysis further revealed that more than 66.58% of students agreed that the PjBL-STEM model helped them practice critical thinking skills, 14.02% strongly agreed, and only 2.07% disagreed with the implementation of PjBL-STEM as a means of enhancing students' critical thinking abilities.

Based on classroom observations conducted at SMA Negeri 1 Sindangwangi, the researcher applied the Luby-Rush version of PjBL-STEM, which consisted of five stages. First, orienting students to the problem: students were presented with a real phenomenon related to environmental issues to stimulate their curiosity (Science). Second, information seeking: after identifying the environmental problem, students were asked to gather information from various sources to solve the problem. They then listened to the teacher's explanation of the learning activities, including group discussions on the issues presented. Third, guiding investigation and problem-solving: students analyzed data and information on exothermic and endothermic reactions provided in the worksheets to construct concepts for addressing the problem. Fourth, developing and testing solutions: students recorded the results of their discussions on exothermic and endothermic reactions, designed an experimental procedure, and conducted a practical activity by creating eco-friendly soap to be compared with commercial detergents (Technology and Engineering). Fifth, presenting results and drawing conclusions: students presented the calculation results of their experiments (Mathematics), followed by a closing session in which both teacher and students formulated the lesson's conclusion. This process reflects the principles of critical thinking, problem formulation, and the 4C skills (critical thinking, creativity, collaboration, communication).

These findings are consistent with the study of Ade Fitriyani (2020), who found that the implementation of PjBL-STEM could improve students' higher-order thinking skills by offering opportunities to understand the importance of integrating multiple disciplines and their applications. The PjBL-STEM model, therefore, has strong potential to foster students' critical thinking skills through its inherent characteristics. The research results confirmed that there was a significant Increase In critical thinking skills in the experimental class after the application of PjBL-STEM. Students' pre-test scores, initially categorized as low, improved to good after the treatment. The environmental issue chosen in this study was the harmful impact of detergent waste, which students were asked to address by designing a project-based solution leading to the production of an alternative product. The final project assigned to students was the creation of an eco-friendly detergent, with the following tools and materials:

4. Tools
   4.1 Bottle
   4.2 Cup
   4.3 Styrofoam
   4.4 Thermometer
   4.5 Knife
5. Materials
   5.1 Soapberry fruit (*lerak*)

5.2 Durian peel
5.3 Water

The researcher also designed a workflow for the detergent-making project, which was later compared with the students' own project designs. The procedure was as follows:

1. Prepare a bottle with a lid.
2. Put an adequate amount of soapberry fruit into the bottle.
3. Add 50–100 ml of water.
4. Let it sit for 20–30 minutes.
5. Shake the bottle until foam appears.
6. The eco-friendly detergent is ready to use.
7. Compare the detergent with a commercial detergent to observe and measure its temperature.

Below we present the manufacturing procedure in Figure 5.

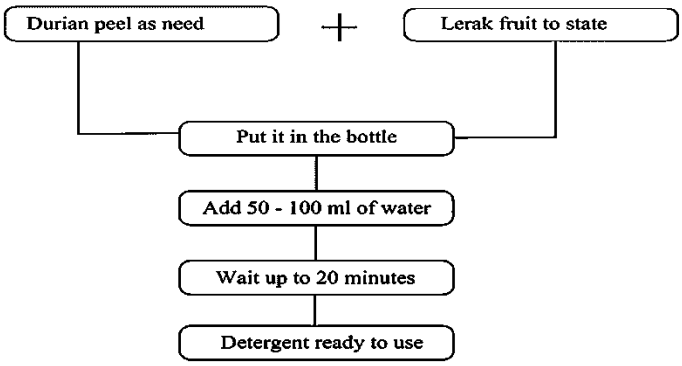

Figure 5. Researcher Project Design Result

In the implementation of STEM-integrated learning on thermochemistry, the Science aspect was represented by the subject matter itself. In this study, the experimental class was divided into six groups, each tasked with carrying out a project aimed at addressing an on going environmental issue. As part of the project, students were required to design and develop a project plan utilizing current technological tools, such as the *Canva* application. Group 1 demonstrated noticeable progress. Durring the first meeting, students were able to generate and present ideas to be developed into a project aimed at solving the identified environmental problem. They also created a workflow design, which was developed through the use of Technology. The following is an example of a project design created by students using the *Canva* application which can be seen in image 6.

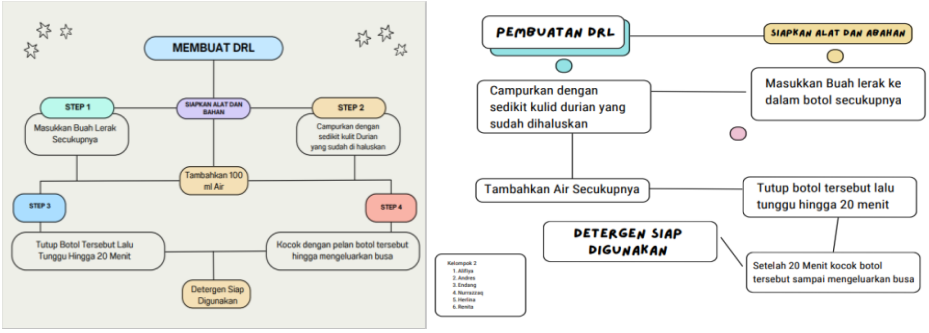

Figure 6. Student Project Design Results

From the results of the project designs carried out by each group, it can be concluded that the Technology component in the STEM-integrated learning process was successfully implemented. After completing the design stage, students proceeded to develop the project based on the plans created by their respective groups. The project focused on the production of an Eco-Friendly Detergent (EFD) made from *soapberry (Sapindus rarak)* and durian peels. This project was selected because approximately 86% of farmers in the region are durian farmers, making durian peels a highly available resource. Durian peels were chosen as a primary ingredient due to their saponin content, which makes them suitable as a natural cleaning agent. At present, durian peels remain largely underutilized, and their application in detergent production provides both an environmentally friendly solution and added value for local communities. This is in line with the findings of Gusman (2023), which show that STEM-based learning is highly effective in chemistry instruction and can enhance students' critical thinking skills. This was evident in the implementation of learning in the experimental class, which applied STEAM-based learning through the Evaluate phase of its syntax. At this stage, the researcher guided students to analyze, evaluate, and draw conclusions from their learning outcomes based on the construction of molecular structures using the ChemSketch application. The following is documentation of the the implementation of the project carried out by students, as seen in figure 7.

Figure 7. Making Exvironmentally Friendly Detergents

After completing the production of the eco-friendly detergent, each group was assigned to compare the temperature of the detergent they had created with commercially available detergents. This comparison was conducted using a simple calorimetry devide designed by the students as part of the Engineering component

of the STEM approach. The design of this simple calorimeter was intended to examine the relationship with the thermochemistry topic being studied, specifically exothermic and endothermic reactions. Through this activity, students aimed to determine whether the detergents released heat (exothermic) or absor heat (endothermic) during testing. Below is the illustration of the device designed by the students, along with the documentation of the temperature measurement process used to compare the Eco-Friedly Detergent (EFD) with other common detergent samples used in daily life. The following is documentation of the implementation of the project carried out by students, as seen in figure 8.

Figure 8. making a Simple Tool for Temperature Measurement

Afher measuring the temperature using a simple calorimetry tool, the results obtained by each group are presented in the following table. In the context of STEM-based learning project, this stage is a component of Mathematics, as it involves the presentation and analysis of experimental data. The following table show the measurement results from each group's experiment. The following is a presentation of the students'work, as seen in figure 9.

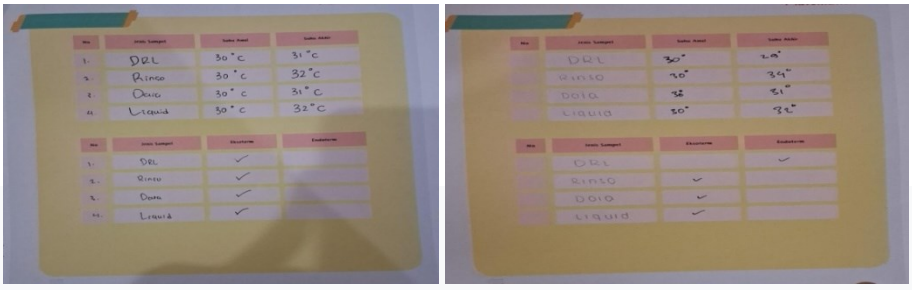

Figure 9. Student Temperature Measurement Results

After the learning implementation, the researcher presented the results of students' critical thinking skills. Before the treatment, the initial average score was 44%, while after the treatment, the average score increased to 77%. This finding is in line with the study conducted by Ilyas Yusuf (2022), which showed that students' learning motivation scores improved positively after being taught through the STEM approach. The improvement was reflected in the change of the lowest score from 58 to 62, the highest score from 89 to 97, the class average from 71.57 to 80.83, and the median score from 71.50 to 78.00. Based on these categories, students' critical thinking ability, measured classically, indicated that before the

treatment the average learning motivation fell into the high category (interval 60–80). After the treatment, the average score was classified as very high (interval 80–100). This finding is further supported by the research of Angela, S. A. (2025), who explained that mathematical critical thinking is a process of generating new ideas to solve problems with more than one possible solution. STEM is a learning approach that integrates four disciplines—Science, Technology, Engineering, and Mathematics—and connects conceptual knowledge with real-world applications through the principles of science, mathematics, engineering, and technology. As a result, STEM enables students to easily understand, analyze, and think critically in solving contextual problems in everyday life.

Similarly, Ade Fitriyani (2020) found that Project-Based Learning (PjBL) integrated with STEM had a significant influence on students' critical thinking skills. This is because the PjBL-STEM model requires students to actively learn and directly engage in the learning process. In its application, the PjBL model integrated with STEM is implemented according to the PjBL-STEM syntax proposed by Laboy-Rush (2010). tudents' responses in a learning process are highly important, as they allow researchers or teachers to determine whether the applied treatment can be accepted or rejected. Therefore, the researcher distributed a questionnaire consisting of 17 statements regarding the implementation of the applied learning model. The student response questionnaire was administered only to the experimental class.

The analysis of the questionnaire results showed that none of the students gave a negative response toward the implementation of the Project Based Learning (PjBL) model integrated with STEM in the thermochemistry topic. This indicates that the learning model was well-accepted by the students and provided them with an engaging experience through the projects they carried out. Furthermore, the results revealed that more than 66.58% of students agreed that the integration of PjBL with STEM helped them develop critical thinking skills, and 14.02% strongly agreed with its implementation. Only 2.07% of students disagreed with the statement that the PjBL-STEM model could enhance their critical thinking skills. These findings are consistent with the study conducted by Ramdhan (2022), which reported students' responses to learning with a STEM approach in the ecosystem topic. The study explained that the strongest student response appeared in the indicator of using the STEM approach, with an average percentage of 83%, categorized as very good. Overall, student responses showed a very positive result, with an average response score of 82%, also categorized as very good.

4. Conclusion

Based on the findings of this study, the researcher proposes several suggestions as follows:

1. Student activities during the learning process need to be further enhanced, and learning should not be solely teacher-centered. Increasing student

engagement, such as designing more interesting projects, can foster curiosity and active participation.
2. The Project Based Learning (PjBL) model integrated with STEM can be applied in future research and is also recommended for use in other chemistry topics or even in different subject areas.
3. Students' critical thinking skills need to be explicitly taught as essential preparation for their future. This is because students will encounter various real-life problems that require creative and critical solutions.

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How to cite this article:

Gusman, T. A., Sodikin., & Cahyani, M. D. (2026). The Implementation of STEM-Integrated Project-Based Learning (Pjbl) to Improve Students' Critical Thinking Skills. *Journal of Educational Sciences*, *10(1)*, 71-84.