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The Effect of STEM-Based Project-Based Learning (PjBL) on Students' Scientific Thinking Skills in Reaction Rate

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Abstract

Reaction rate is one of the most complex topics in chemistry and remains difficult for students to understand. This condition highlights the need for more effective instructional approaches to enhance students' scientific thinking skills.This study was conducted to analyze the effect of implementing the STEM-based Project-Based Learning (PjBL) model on the scientific thinking skills of Grade XII students in the topic of reaction rates. The research employed a quasi-experimental method using a non-equivalent control group design involving 52 students divided into an experimental class and a control class. The research instrument consisted of nine essay questions with a high level of reliability, as indicated by a Cronbach's Alpha value of 0.740. The findings revealed that the implementation of the STEM-based PjBL model significantly enhanced students' scientific thinking skills. This improvement was evident across all indicators measured in the experimental class, including the logical indicator, which reached 75.9%, the analytical indicator at 68.1%, the systematic indicator at 59.1%, the deductive indicator at 59.9%, and the inductive indicator, which increased to 68.1%. Furthermore, the effect size analysis yielded a score of 1.632, which falls into the very large category. Therefore, it can be concluded that the implementation of the STEM-based Project-Based Learning (PjBL) model had a very strong effect on improving students' scientific thinking skills.

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1. INTRODUCTION

Chemistry plays a strategic role in developing scientific literacy and reasoning among students; however, several of its topics are abstract and demanding, making them difficult to master at the secondary school level. Reaction rate is one of the particularly challenging topics in the Phase F learning outcomes of senior high school (SMA/MA), as it requires students to transform abstract concepts into concrete representations (Silvi Busada & Faizah Qurrata Aini, 2024). Classroom settings, students are consistently reported to encounter substantial difficulties with this topic, as evidenced by their limited ability to explain phenomena across multiple levels of representation and their inability to connect experimental data with theoretical models. For the purpose of this introduction, students are still reported to experience significant difficulties with this topic, as evidenced by limited ability to explain phenomena across representational levels and challenges in connecting experimental data with theoretical models (Salahudin et al., 2025). In the learning process, these comprehension difficulties can lead to misconceptions and negatively affect students' learning outcomes. This condition is influenced by prior conceptions, which refer to the knowledge or initial understanding that students already possess before attending classroom instruction, such as previous material related to reaction rates, namely stoichiometry (basic chemical calculations)(Anwar, 2020).

Reaction rate is a complex topic that requires multiple representations in the learning process. In studying reaction rates, students experience difficulties because the material is related to their mathematical and physical abilities.(Arsyka, A. T. Z., & Wahyuni 2021). Because of its broad breadth, reaction rate content essentially necessitates a solid grasp and command of fundamental ideas. Students' inability to define and explain chemical occurrences using different levels of representation is one of the factors causing them to struggle with the content (Safitri et al., 2019).

Conceptually, the Reaction rate is widely recognized as one of the chemistry topics that students often perceive as difficult to understand, determined by the rate law and the order of each species, and closely related to the rate constant and collision theory. Nevertheless, numerous studies have shown that conceptual misconceptions and procedural errors remain prevalent, such as interpreting the reaction order as stoichiometric coefficients and equating reaction time with reaction rate (Marthafera et al., 2018). These conditions indicate that students' understanding of reaction rate still needs to be reinforced through more meaningful learning strategies.

The reaction rate topic holds broad relevance across various applied contexts. In industry, environmental science, and health, controlling reaction rates determines process quality and safety. Catalysis, for instance, forms the foundation of efficient reaction design across numerous sectors, including pharmaceuticals. Analyses of textbook instructional materials have also shown how concepts of catalysts and reaction energy pathways are explained to emphasize their practical implications, such as reaction acceleration in therapeutic design (Sakti et al., 2020). Furthermore, at the pedagogical level, research on contextual learning strategies has reported that approaches linking reaction rate content with cultural realities and learning environments are capable of improving students' motivation and learning outcomes (Basit et al., 2023). These findings reinforce the rationale that strengthening contextual relevance and the authenticity of learning tasks is essential to facilitate stable meaning construction in the topic of chemical kinetics.

In alignment with these needs, science education at the secondary level must not only focus on procedural mastery but also requires the development of scientific thinking skills. Scientific thinking is a process of reasoning systematically and based on empirical evidence toward a specific object, generating scientifically valid knowledge. This process encompasses not only logical and empirical reasoning but also demands acquisition of knowledge and its real-life application (Wulandari, 2017). Scientific thinking skills are therefore essential for understanding reaction rate, as this topic requires students to think systematically and factually when analyzing changes occurring during chemical reactions. Through scientific thinking, students can observe the effects of various factors-such as concentration, temperature, surface area, and catalysts-on reaction rates in a logical and empirically grounded manner.

Scientific thinking skills can be defined as a person's capacity to apply scientific methods in systematically and logically searching for, analyzing, and interpreting information, with the aim of obtaining objective and accountable understanding and conclusions. These skills encompass several key stages, including observation, formulation of research questions and hypotheses, conducting experiments, data collection and analysis, drawing conclusions, and effectively communicating findings (Maharani & Muna 2024) In this study, the scientific thinking variable was analyzed based on five aspects: logical, analytical, systematic, deductive, and inductive thinking.

A study conducted by (Inggriyani, F., & Putri 2026) demonstrated that the use of the Project-Based Learning (PjBL) model markedly contributed to the enhancement of students' competencies the and promoted the development of creativity, collaborative abilities, and critical thinking. The procedural stages of applying the Project-Based Learning (PjBL) approach steps, include: determining the driving question, designing the project, scheduling project implementation, monitoring project progress, assessing outcomes, and evaluating the project and its results (Muhibbullah et al., 2024).

The implementation of a Project-Based Learning (PjBL) model centered on STEM disciplines represents an instructional methodology that integrates scientific, technological, engineering, and mathematical principles with methodologies inherent to project-based learning. This model is designed to encourage students to design, implement, and present projects that integrate STEM concepts in an interdisciplinary manner. This method significantly improves scientific attitudes and fosters the growth of 21st-century skills including creativity, teamwork, and critical thinking. (Masykuri, 2024).

According to Alhayat et al (2023), the Project Based Learning (PjBL) model has several advantages that make it effective in improving the quality of students' learning processes and outcomes, although it also has several limitations that should be taken into consideration. The advantages of implementing the Project Based Learning (PjBL) model include improving

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students' academic achievement, increasing students' interest and engagement in the learning process, and encouraging students to think critically and innovatively. However, the limitations include requiring a relatively long period of time, not all subject topics being suitable for project-based instruction, and the need for adequate facilities and learning resources.

STEM education is educational approach incorporates four academic fields: science, technology, engineering, and mathematics. Through STEM education, the learning process aims to connect knowledge concepts with real-world situations through the application of scientific principles from relevant fields (Angela & Rahayu, 2025).

The integration of science, technology, engineering, and mathematics constitutes STEM education, developing a curriculum that emphasizes addressing practical and professional issues. (Suwardi, 2021). The aim of STEM education is to equip students with the ability to conduct research, identify, explore, and answer questions in a systematic and independent manner. This procedure aims to furnish learners with fundamental skills pertinent to the 21st century, encompassing analytical and inventive reasoning, originality, issue resolution, effective articulation, and collaborative effort (Kırıcı & Bakırcı, 2021). Through STEM education, students are encouraged to face various real-world challenges with relevant and useful disciplinary skills (Lafifa et al., 2023. The integration of Project-Based Learning (PjBL) and STEM is considered particularly effective because it combines project-based activities with interdisciplinary problem solving in authentic contexts. Unlike other active learning approaches that primarily emphasize discussion, problem solving, or conceptual understanding, PjBL-STEM requires students to investigate real-world problems, design and test solutions, analyze evidence, evaluate outcomes, and communicate their findings through an iterative learning process. As a result, students continuously engage in logical reasoning when identifying relationships among concepts, analytical thinking when interpreting data, systematic thinking when planning and implementing each stage of the project, deductive reasoning when applying scientific principles to predict outcomes, and inductive reasoning when drawing conclusions based on empirical evidence obtained from experiments. This integrated learning process provides a more comprehensive environment for developing scientific thinking skills because each stage of the project naturally requires students to employ multiple scientific reasoning processes in an integrated manner, rather than focusing on a single cognitive skill.

Consequently, this research endeavored to explore the influence of the Project-Based Learning methodology on the scientific reasoning proficiencies of twelfth-grade students concerning the topic of reaction rates at SMA Negeri 2 Gorontalo Utara.

2. METHOD

2.1. Research Design

This investigation utilized a quasi-experimental methodology, comprising an experimental cohort and a control cohort, to evaluate variations in learning results subsequent to the introduction of the intervention.

In the experimental group, students were first administered a pretest to determine their initial abilities before the learning process began. Subsequently, they received a treatment in the form of the implementation of a particular learning model, followed by a posttest to measure the improvement in their abilities after the treatment was applied. Meanwhile, students in the control group were also given a pretest and a posttest; however, they did not receive any special treatment. Instruction in the control group was conducted using the conventional teaching model through the lecture method.

This research involved two categories of variables, namely the independent variable and the dependent variable. The STEM-based Project-Based Learning (PjBL) approach served as the independent variable, while students' scientific thinking abilities on the reaction rate material functioned as the dependent variable.

2.2. Participant

The research population comprised all Grade XII students enrolled in the chemistry specialization at SMA Negeri 2 Gorontalo Utara in the 2025/2026 academic year, totaling two classes. Sampling was conducted based on practical considerations, including constraints related to time, budget, and available resources. Based on these considerations, one class was assigned to the experimental group and received the STEM-based Project-Based Learning (PjBL) intervention, whereas the other class was assigned to the control group and received conventional instruction. (Mardhiyah et al., 2025).

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This Research using all Grade XII students, totaling 52 students, enrolled in the chemistry specialization at SMA Negeri 2 Gorontalo Utara across two classes is XIIA dan XIIC.

2.3. Instruments

This research employed two types of instruments: a treatment instrument and a test instrument. The treatment instrument used in this study was a teaching module (modul ajar) developed in accordance with the Merdeka Curriculum Phase F, following the learning steps and syntax of the STEM-integrated Project Based Learning (PjBL) approach. The test instrument consisted of nine essay items representing each indicator of scientific thinking skills and reaction rate content indicators.

Prior to use, all instruments underwent a pilot test to evaluate their feasibility. The validation process included content validity assessment conducted by three validators, namely La Alio, S.Pd., M.Si., Dr. Wiwin Rewini Kunusa, S.Pd., M.Si., and Rahmat Utina, S.Pd., M.Pd., Gr., as well as empirical validation through an instrument pilot test.

2.4. Data Analysis

Descriptive analysis using percentage scores was applied to assess students' scientific thinking abilities before and after the implementation of the STEM-based PjBL approach. This analysis served to present the data in percentage form, enabling a clear depiction of the changes and outcomes derived from the collected data.

Data collected from the pretest and posttest results were then dihitung menggunakan *effect size* (Widyastuti & Airlanda, 2021). According to the effect size criteria, a value of $0<d<0.2$ is classified as a low or small effect. A value of $0.2<d\leq0.5$ indicates a moderate effect. Furthermore, a value of $0.5<d\leq0.8$ represents a high effect, while a value of $d>0.8$ falls into the category of a very high effect.

3. RESULT AND DISCUSSION

3.1. **Result**

Students' scientific thinking skills were evaluated through pretest and posttest assessments. The pretest was conducted to identify students' initial understanding prior to the application of the STEM-based Project Based Learning (PjBL) approach, while the posttest was administered after the learning activities to determine students' scientific thinking abilities following instruction. Based on the analysis of the mean pretest and posttest scores, the results for each indicator of scientific thinking in both the control and experimental classes are presented in Table 1.

Table 1. Percentage (%) of scientific thinking skill indicators: pretest and posttest results for the control and experimental groups.

No	Scientific Thinking Indicator	Percentage of Students' Scientific Thinking Score (%)			
		Control Class		Experimental Class	
		Pretest	Posttest	Pretest	Posttest
1	Logical	54.3	64.1	61.2	75.9
2	Analytical	45.9	61.7	51.1	68.1
3	Systematic	39.1	53.8	45.7	59.1
4	Deductive	33.7	54.4	47.4	59.9
5	Inductive	40.2	58.7	50.0	68.1

Table 1 shows that all indicators of scientific thinking skills improved after the learning process. However, the post-test scores for the systematic (59.1%) and deductive (59.9%) indicators remained lower than that of the logical indicator (75.9%). This finding suggests that systematic and deductive thinking skills were more difficult for students to master than the other indicators.

The relatively low achievement in the systematic thinking indicator can be attributed to the fact that this skill requires students to solve problems in a structured and sequential manner. In the reaction rate topic, students were expected to determine the appropriate experimental procedures, relate their observations to the underlying scientific concepts, and draw conclusions based on the data obtained. However, many students still experienced difficulties in connecting these stages coherently, resulting in a less substantial improvement in their systematic thinking skills.

Similarly, the deductive thinking indicator also achieved a relatively low score because this skill requires students to apply previously learned concepts or theories to explain phenomena or solve problems. In the context of reaction rate, for example, students needed to apply collision theory to explain why changes in temperature, concentration, or surface area influence the rate of reaction. Many students tended to memorize the concepts without fully understanding how to apply them in different contexts, which contributed to the slower development of their deductive thinking skills.

In contrast, the logical thinking indicator obtained the highest score because students were frequently engaged in observing experimental results, participating in discussions, and providing evidence-based explanations throughout the learning process.

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These activities enabled students to establish logical connections between their observations and the scientific concepts being studied. Therefore, although all indicators showed improvement, systematic and deductive thinking skills still require more frequent practice through structured inquiry and step-by-step problem-solving activities.

The influence of the STEM-based Project-Based Learning (PjBL) model on students' scientific thinking abilities in this study was examined using a t-test. Before performing the analysis, prerequisite tests were first conducted, namely normality and homogeneity tests.

A paired-samples t-test was then applied to identify the mean differences between students' pretest and posttest scores in scientific thinking skills after instruction using the STEM-based PjBL model.

The results of the hypothesis testing show that the obtained significance value is 0.001, which is lower than the significance level of 0.05 (0.001 < 0.05). In addition, the calculated t-value of 8.295 is higher than the critical t-value at a significance level of α = 0.05 with 28 degrees of freedom, which is 2.04841 (8.295 > 2.04841). Therefore, the null hypothesis (H_0) is rejected. These findings indicate that there is a significant mean difference in students' scientific thinking skills between the pretest and posttest after the implementation of the STEM-based PjBL model in the learning process. An independent-samples t-test was performed to examine the difference in students' scientific thinking skill mean scores between the experimental and control groups.

Results of the normality test showed values exceeding 0.05, confirming the normal distribution of the data. The homogeneity test produced results indicating produced values above 0.05, indicating homogeneous variance between classes. With both assumptions fulfilled, a parametric independent sample t-test was performed, as explained above.

The results of the independent samples t-test show that the obtained significance value is 0.000, which is lower than the significance level of 0.05 (0.000 < 0.05). In addition, the calculated t-value of 2.268 is higher than the critical t-value at a significance level of α = 0.05 with 50 degrees of freedom, which is 2.00856 (2.268 > 2.00856). Therefore, the null hypothesis (H_0) is rejected. This indicates that there is a significant difference in the mean scientific thinking skills between the experimental class and the control class.Effect size analysis was conducted to determine the magnitude of the impact of the STEM-based PjBL model on students' scientific thinking abilities in the reaction rate topic.

The mean learning outcome after implementation of the STEM-based PjBL model was higher than before implementation. This is demonstrated in the Paired Sample Statistics table, where the mean score before the mean pretest score prior to implementing the STEM-based PjBL model was 17.62, which increased to 23.24 following its application.These results confirm that the model exerted a considerable and statistically significant beneficial effect on students' scientific thinking skills. The effect size calculation is d = 1,632.

Based on the effect size computation, a value of 1.632 was obtained, which is categorized as "very large." Thus, the application of the STEM-based PjBL model had a substantial impact on students' scientific thinking abilities.

3.2. Discussion

The results showed that the application of the STEM-based Project-Based Learning approach significantly enhanced students' scientific thinking abilities in the reaction rate topic. The hypothesis test yielded a significance value of 0.000, which is lower than 0.05, resulting in the rejection of H_0 and acceptance of H_1. Thus, the STEM-based PjBL model had a real and significant impact on students' scientific thinking abilities. The magnitude of this effect was further quantified using the *effect size*. Based on the calculation results, the *effect size* test, which yielded a value of 1.632—exceeding the 0.8 threshold and categorized as "very large." This indicates that the STEM-based PjBL approach had a significant influence on students' scientific thinking skills. A higher *effect size* value reflects greater treatment effectiveness in the study.

Improvements in scientific thinking skills were also evident from the pretest-posttest comparison across all indicators. On the logical thinking indicator, mean scores rose from 61.2% to 75.9%, reflecting enhanced use of sound reasoning and understanding of cause-and-effect relationships in solving reaction rate problems. On the analytical indicator, scores increased from 51.1% to 68.1%, demonstrating improved capacity to identify, decompose, and analyze factors influencing reaction rates.

The systematic thinking indicator improved from 45.7% to 59.1%, reflecting greater ability to organize problem-solving steps in a structured and sequential manner. The deductive indicator rose from 47.4% to 59.9%, signaling enhanced skill in drawing conclusions based on learned theories. The inductive indicator increased from 50.0% to 68.1%, demonstrating improved proficiency in formulating generalizations from observational data and evidence.

These improvements occurred because the STEM-based PjBL model afforded students opportunities to engage actively in the learning process through project-based activities. During the problem identification phase, students were guided to identify real-world problems relevant to reaction rate concepts. Subsequently, in the project design and implementation phases, students conducted experiments, collected data, and analyzed their findings. These activities fostered the development of logical, analytical, and systematic thinking skills. Furthermore, the integration of STEM elements helped students connect scientific concepts with technology, engineering, and mathematics in solving contextual problems.

The results of this investigation align with those of (Windasari et al., 2020) who reported that the STEM-integrated PjBL model positively affected students' higher-order thinking skills. These converging findings indicate that innovative instructional models exert a notable impact on pupils' capacity for scientific thought. Additionally, it has been demonstrated that the STEM-based PjBL approach enhances students' critical thinking abilities in the reaction rate topic. The consistency of these findings further confirms the effectiveness of implementing STEM-integrated project-based learning in enhancing students' cognitive abilities.

Nevertheless, certain limitations were encountered during the study, including time constraints in project completion and the relatively low participation of some students in group discussions. These limitations were minimized through intensive teacher guidance and clear task distribution within groups.

Overall, the STEM-based PjBL model demonstrated efficacy in improving pupils' capacity for scientific thought. on the reaction rate topic. It is therefore recommended as an innovative, active, and meaningful alternative approach to chemistry instruction that can improve both the effectiveness of the learning process and students' academic achievement.

4. CONCLUSION

The results of the study indicated a statistically meaningful variation in scientific thinking skills between students taught using conventional instruction and those taught through the STEM-based PjBL approach. This difference was demonstrated by the effect size of students' scientific thinking skills following the application of the STEM-integrated Project-Based Learning approach, as well as the increase in average scores from pretest to posttest. Statistical analysis employing both paired-samples t-test and independent samples t-test produced a probability value of 0.000, which is lower than 0.05, leading to the rejection of H_0 and acceptance of H_1. Therefore, it can be concluded that the STEM-based Project-Based Learning (PjBL) model significantly enhanced students' scientific thinking abilities in the reaction rate topic.

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