



The Effect of STEM-Based Media on Students Scientific Literacy Skills in Reaction Rate Topic

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Abstract: **The Effect of STEM-Based Media to Improve Students Science Literacy Skills on the Reaction Rate Topic.** This study aims to analyze the effect of using STEM (Science, Technology, Engineering, and Mathematics)-based learning media on improving students' scientific literacy. The method used was a quasi-experiment with a two-group Pretest-Posttest design. The sample was selected through a purposive sampling technique, data were collected through a science literacy test instrument and analyzed using a t-test (α 0.05) and N-gain calculation. The results showed that the use of STEM-based media significantly improved students' scientific literacy with N-gain scores (0.7742) in the high category compared to the control class. It can be concluded that the integration of STEM-based virtual lab media is very feasible and effective as an innovative solution for visualizing complex chemical concepts. Based on the results of this study, it is recommended that the use of STEM media to optimize students' scientific competence in facing the development of science and technology

Keywords: STEM learning, virtual laboratory, scientific literacy, reaction rate

Abstrak: **Pengaruh Media Berbasis STEM untuk Meningkatkan Keterampilan Literasi Sains Siswa pada Materi Laju Reaksi.** Penelitian ini bertujuan untuk menganalisis pengaruh penggunaan media pembelajaran berbasis STEM (Science, Technology, Engineering, and Mathematics) terhadap peningkatan literasi sains siswa. Metode yang digunakan adalah eksperimen semu (quasi-experiment) dengan desain two group Pretest-Posttest design. Sampel dipilih melalui teknik purposive sampling, data dikumpulkan melalui instrumen tes literasi sains dan dianalisis menggunakan uji-t (α 0.05) serta perhitungan N-gain. Hasil penelitian menunjukkan bahwa penggunaan media berbasis STEM secara signifikan meningkatkan literasi sains siswa dengan capaian skor N-gain (0.7742) pada kategori tinggi dibandingkan kelas kontrol. Dapat disimpulkan bahwa integrasi media virtual lab berbasis STEM sangat layak dan efektif sebagai solusi inovatif untuk memvisualisasikan konsep kimia yang kompleks. Berdasarkan hasil penelitian ini merekomendasikan penggunaan media STEM untuk mengoptimalkan kompetensi saintifik siswa dalam menghadapi perkembangan IPTEK.

Kata kunci: Pembelajaran STEM, Virtual Laboratorium, Literasi Sains, Laju Reaksi.

▪ INTRODUCTION

The rapid development of information technology demands that the world of education prepare a generation with adequate science and technology (IPTEK) skills to face the challenges of the 21st century (Rihmahwati et al., 2024). One of the essential needs that students must possess today is scientific literacy skills to be able to fully participate in a knowledge-based society. Scientific literacy is not just the ability to understand scientific phenomena, but also the ability to interpret data and relate scientific concepts to everyday life (Nurlaili et al., 2023; Purnawati & Yakin 2025). The importance of scientific literacy is also an indicator of global education quality through international assessments such as PISA.

The state of student scientific literacy in Indonesia still requires serious attention. According to the 2022 PISA report, Indonesia ranked 62nd out of 81 countries with an average score of 415, still far below the OECD average of 500 (OECD, 2023). A similar situation was found at MAN 3 Medan, where initial student scientific literacy tests showed an average score of only 65 out of an ideal score of 100. Furthermore, student learning outcomes on reaction rates were also low, with 78.1% of students scoring below the Minimum Competency (KKM) (78). This low achievement was caused by the learning process, which tended to be theoretical, the limited use of learning resources in textbooks, and student boredom in participating in class discussions.

Reaction rate is a difficult chemistry topic to understand due to its abstract nature and the demand for mathematical skills and experimental data analysis. This material requires students to understand the relationship between substance concentration, time, and various factors that influence the speed of chemical reactions. Furthermore, students are required to be able to read graphs, interpret experimental data, and predict changes in reaction rates under certain conditions (Sidauruk & Anggraeni, 2024). The main obstacle in learning this material is the limited availability of real-world laboratory facilities, which rarely allow students to conduct practical work that could hone their science process skills (Pane et al., 2024). Without practical work, students struggle to connect abstract chemical concepts with the realities of everyday life (Akbar et al., 2024).

To address this gap, innovative learning media are needed that can bridge the limitations of real-world practicums while simultaneously improving students' scientific literacy. One potential solution is the integration of virtual lab media into STEM (Science, Technology, Engineering, and Mathematics)-based learning. The STEM approach is effective because it integrates cross-disciplinary knowledge and emphasizes problem-solving and higher-order thinking skills (Mbuik et al., 2025). Previous studies have shown that STEM-based learning and virtual laboratory media can improve students' scientific literacy and conceptual understanding (Supardi et al., 2025; Pryanti & Nasrudin, 2022; Drastisianti et al., 2024; Rahmi et al., 2023). However, most studies tend to examine these approaches separately or focus on general science topics, with limited emphasis on their integration in specific chemistry materials such as reaction rates. In addition, previous research has not fully explored their implementation in schools with limited laboratory facilities. Therefore, this study integrates STEM-based learning with virtual lab media (PhET simulations) to improve students' scientific literacy on reaction rate topics, providing a more contextual and applicable contribution to chemistry learning.

The novelty of this research lies in the combination of the STEM approach with virtual lab (PhET) media specifically to improve students' scientific literacy on reaction rate topics at MAN 3 Medan, which has previously relied solely on textbooks. Based on this background, this study aims to determine the significant effect of STEM-based

learning using virtual lab media on students' scientific literacy skills and analyze student improvements and responses to the use of virtual lab media (PhET simulations) in STEM-based learning.

Literature Review

Chemistry learning is an educational process that occurs through interactions between students, educators, and learning resources within a structured learning environment. The learning and teaching processes are interconnected, with learning understood as an internal activity of students, while teaching serves as a systematic means to achieve educational goals (Suarim & Neviyarni, 2021). Therefore, chemistry learning needs to be designed contextually to facilitate the formation of meaningful conceptual understanding. Chemistry learning emphasizes changes in student behavior, encompassing cognitive, affective, and psychomotor aspects through planned learning experiences. Learning is viewed as the process of acquiring knowledge, skills, and positive attitudes acquired through active interaction with the learning environment (Harefa, 2023). In the context of chemistry learning, these changes are measured not only by mastery of concepts but also by students' ability to apply concepts to solve scientific problems (Sugiharti & Zen, 2020).

Chemistry has unique characteristics, such as its abstract, hierarchical nature, and dynamic development. Many chemical concepts involve microscopic representations that cannot be directly observed, such as atoms, molecules, and chemical reaction mechanisms (Rosmiati, 2022). Students often experience difficulties in understanding abstract chemical concepts, therefore appropriate learning media are needed to support visualization and improve understanding (Juwita & Darmana, 2025). These characteristics require approaches and media that can bridge abstract concepts with students' concrete understanding.

As technology advances, digital-based learning media is increasingly being utilized in science learning. Digital media not only serves as a means of conveying information but also encourages active student participation through interactive simulations and visualizations (Prastowo, 2021). The integration of visual and verbal elements in digital media is considered capable of reducing students' cognitive load in understanding complex chemical concepts (Susanto & Suryana, 2022).

One relevant digital learning medium for chemistry learning is the virtual laboratory. A virtual lab is a technology-based learning environment that allows students to conduct virtual experimental simulations without having to be in a physical laboratory (Raman et al., 2022). Virtual labs provide a more flexible, safe, and efficient alternative to practical learning, especially for schools with limited laboratory facilities (Lestari et al., 2023).

The use of virtual labs in chemistry learning is considered effective in helping students understand abstract and complex concepts. Through visualization of reaction processes and variable manipulation, students can observe chemical phenomena more clearly and systematically (Sanimah et al., 2024). However, virtual labs still have limitations in directly practicing laboratory skills, so their use must be tailored to learning objectives.

PhET simulations are one form of virtual lab widely used in science learning. PhET is a computer-based interactive simulation medium designed to support learning through independent exploration and discovery of concepts (Abdjul, 2019). PhET simulations allow students to modify variables, observe experimental results, and

visualize chemical concepts that are difficult to observe directly (Purwanto et al., 2016). The use of PhET simulations in chemistry learning can increase student engagement and interest in learning. Interactive displays and visual representations that mimic real-world conditions make PhET effective in helping students develop deeper conceptual understanding (Muzana, 2021). Furthermore, PhET also supports independent learning because it can be accessed anytime through digital devices.

The STEM (Science, Technology, Engineering, and Mathematics) approach is an integrated learning approach that integrates four disciplines to develop students' critical thinking, creativity, and problem-solving skills. The STEM approach emphasizes the connection between theoretical concepts and their real-life application through investigation and solution design activities (Bybee, 2023; Helga et al., 2024).

In chemistry learning, particularly in the topic of reaction rates, the STEM approach provides a comprehensive learning framework. The scientific aspects help students understand collision theory and the factors that influence reaction rates. Technology is leveraged through PhET simulations and virtual labs. Engineering is applied in experimental design. Mathematics is used to analyze data and reaction rate equations (Gultom & Amdayani, 2023).

The integration of the STEM approach with virtual media such as PhET and virtual labs has the potential to improve students' scientific literacy. Scientific literacy encompasses the ability to explain scientific phenomena, interpret data, and make evidence-based decisions in everyday contexts (OECD, 2023; PISA, 2022). Thus, STEM-based chemistry learning supported by virtual media is expected to be able to equip students with conceptual understanding and scientific skills that are relevant to the demands of the 21st century.

Based on the theoretical studies described above, this research is built on a conceptual framework in which STEM-based learning functions as an integrative approach that encourages students to think critically, solve problems, and connect scientific concepts with real-life contexts. The use of virtual laboratory media (PhET simulations) supports this process by facilitating the visualization of abstract concepts in reaction rate material and enabling students to explore experimental variables interactively. Through this integration, students are expected to develop scientific literacy skills, particularly in explaining scientific phenomena, interpreting data, and applying scientific knowledge in problem-solving. Therefore, the integration of STEM-based learning with virtual lab media is expected to improve students' scientific literacy skills on reaction rate topics.

▪ **METHOD**

Research Type and Design

This research is a quasi-experimental study. This type of research aims to identify the influence of other variables under strictly controlled conditions (Silitonga, 2013). This type of research is a quasi-experiment presented in a Two-Group Pretest-Posttest Design. This design was chosen to identify the influence of variables under strictly controlled conditions by comparing two groups of classes given different treatments. The experimental class implemented STEM-based learning combined with the use of virtual lab media (PhET simulation), while the control class implemented STEM-based learning without the use of virtual lab media.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experiment	O ₁	X ₁	O ₂
Control	O ₁	X ₂	O ₂

Population and Sample

The population in this study consisted of all eleventh-grade students at MAN 3 Medan, which were divided into seven classes. The sample was selected using purposive sampling technique based on the recommendation of the chemistry teacher. Two classes were selected as research samples, namely class XI-4 as the experimental class and class XI-2 as the control class.

Research Instruments

The test instrument is a tool to measure student learning outcomes (Azizah et al., 2023). The instruments used in this study consisted of test and non-test instruments:
 Test Instrument: A 20-item essay test designed to measure students' scientific literacy indicators in the Reaction Rate topic. Prior to use, this instrument was validated by an expert validator and piloted on students outside the sample to determine its validity, reliability, discriminatory power, and difficulty level.
 Non-Test Instrument: Included an interview sheet and a student response questionnaire. The student response questionnaire used a Likert scale of 1-4 to measure student responses to the use of the virtual lab media.

Research Procedures

The research procedure was carried out in three main stages:
 Preparation Stage: Includes preliminary studies, proposal development, expert consultation, and test instrument validation.
 Implementation Stage: Consists of administering a pretest to both classes, administering the learning treatment (STEM with a virtual lab in the experimental class and STEM without media in the control class), and administering a posttest.
 Final Stage of the Research: Processing and analyzing test data and student responses to draw conclusions.

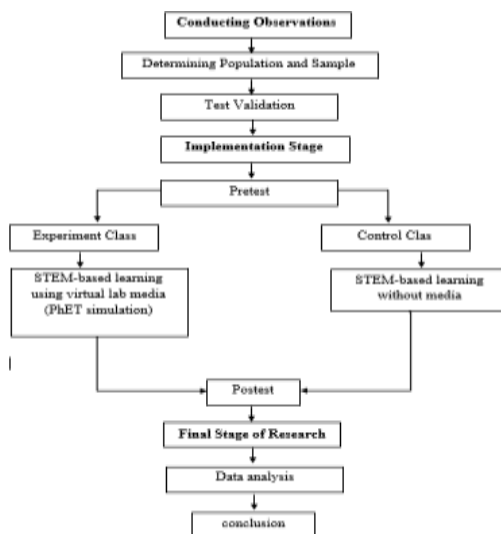


Figure 1. Research Procedure

Data Analysis Techniques

Data were analyzed using descriptive and inferential statistics. Prerequisite analysis tests included a normality test using the Chi-Square test and a homogeneity test using the F-test. Hypothesis testing was conducted using a right-tailed t-test at a significance level of $\alpha = 0.05$ to determine whether there was a significant effect of the use of virtual lab media on students' scientific literacy. Data analysis was performed using Microsoft Excel software.

The improvement of students' scientific literacy skills was analyzed using the normalized gain (N-gain) formula. The N-gain score was calculated using the following formula:

$$\text{N-gain} = \frac{S_{\text{post}} - S_{\text{pre}}}{S_{\text{max}} - S_{\text{pre}}}$$

where S_{post} is the post-test score, S_{pre} is the pre-test score, and S_{max} is the maximum possible score. The N-gain results were then categorized into high, medium, and low criteria.

▪ RESULT AND DISCUSSION

RESULT

Students' scientific literacy skills were measured using pre-tests and post-tests in the experimental and control classes. The pre-test was administered to determine students' initial abilities on reaction rates before the treatment. Based on the pre-test results, the average initial scientific literacy score for students in the experimental class was 40.86 and for the control class, 35.46. These results indicate that students' initial scientific literacy skills in both classes are still relatively low.

After receiving the different treatments, a post-test was administered to determine students' scientific literacy skills after the learning. The experimental class, taught using virtual lab media (PhET simulation) in STEM-based learning, achieved an average post-test score of 87.06, while the control class, taught using STEM-based learning without virtual lab media, achieved an average score of 75.76. These data indicate an increase in students' scientific literacy skills in both classes, with a greater increase in the experimental class.

A comparison of the average pre-test and post-test scores for both classes is presented in Table 2.

Table 2. Average value of student abilities

Class	Pre-Test			Post-Test		
	\bar{X}	S	S^2	\bar{X}	S	S^2
Experiment	40,86	18,75	351,91	87,06	6,14	37,71
Control	35,46	12,41	154,18	75,76	6,70	45,01

Based on Table 2, the results show that both classes experienced an increase in scientific literacy skills, but the increase in the experimental class was higher than the control class, as shown in Figure 2.

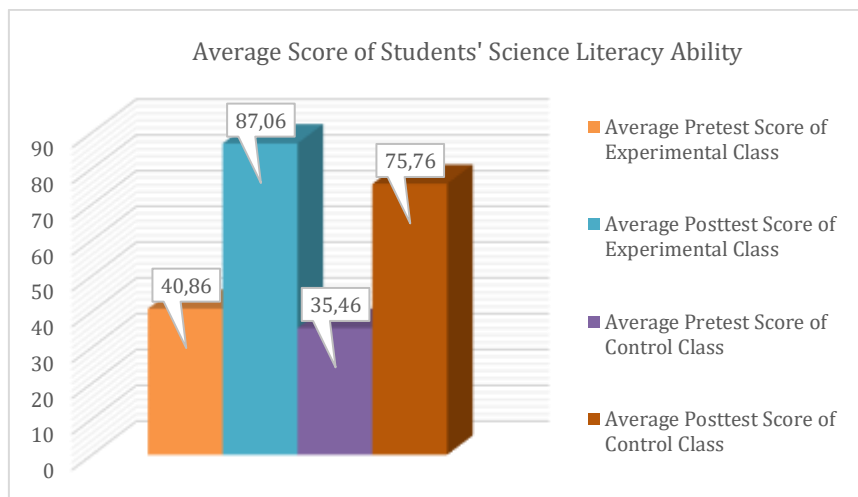


Figure 2. Graph of Students' Average Scores

Research Data Analysis

Normality Test

The normality test for students' scientific literacy skills was conducted using the Chi-Square test with a significance level of 0.05. Data are considered normally distributed if $X_{hit}^2 < X_{table}^2$. The normality test data for the experimental and control classes are shown in Table 3.

Table 3. Normality Test

Class	X_{hit}^2	X_{table}^2	A	Description
Experiment	4,30	11,07	0,05	Normal
Control	9,17	11,07	0,05	Normal

The results of the normality test showed that the calculated χ^2 value in the experimental class was 4.30 and in the control class was 9.17, while the table χ^2 value was 11.07. Because the calculated χ^2 value $<$ the table χ^2 , the data on students' scientific literacy skills in both classes were normally distributed.

Homogeneity Test

A homogeneity test was conducted to determine whether the data from the two samples were homogeneous. This test was performed by comparing the data variances from the two sample groups, using an F-test with a significance level of 0.05. The basis for the F-test decision is that if $F_{hit} < F_{table}$ then the data are homogeneous. The homogeneity test data can be seen in Table 4.

Table 4. Homogeneity Test

Class	F_{hit}	F_{table}	Description
Experiment	1,19	1,86	homogeneous
Control			

The test results showed a calculated F value of 1.19 and a table F value of 1.86. Since the calculated F value < the table F value, it can be concluded that the data on students' scientific literacy skills in both classes are homogeneous.

Hypothesis Test

Hypothesis testing was conducted using a right-tailed t-test with a significance level of 0.05. The purpose of hypothesis testing is to determine whether the hypothesis is accepted or rejected. The test criterion is: if $t_{hit} > t_{table}$, then H_0 is rejected and H_a is accepted.

Table 5. Hypothesis Test

Class	t_{hit}	t_{tabel}	Description
Experiment	6,807	2,045	Ho is rejected and Ha is accepted
Control			

Based on the results of the hypothesis test calculations, it was obtained that t_{hit} was 6.807 and t_{tabel} with a significance level of $\alpha = 0.05$ of 2.045 where $t_{hit} > t_{tabel}$ so that it was obtained that H_0 was rejected and H_a was accepted. So it can be concluded that the scientific literacy skills of students taught by implementing virtual lab media (PhET simulation) in STEM-based learning are higher than students taught with STEM-based learning without virtual lab media.

N-Gain Test

Based on the calculation results, there was an increase in scientific literacy skills after learning using virtual lab media (PhET simulation) in STEM (Science, Technology, Engineering, and Mathematics)-based learning in the experimental class of 0.7742, or 77%, which is categorized as high. This means this treatment resulted in an effective increase. Meanwhile, the increase in scientific literacy skills in the control class of students taught with STEM-based learning without virtual lab media was 0.6209, or 62%, which falls into the moderate category.

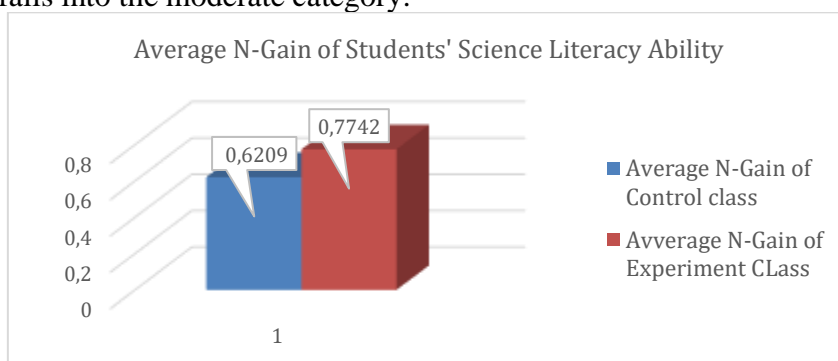


Figure 3. Average N-Gain Graph

Student Responses to Learning

Student responses to the use of virtual lab media (PhET simulations) in STEM-based learning were obtained through a 15-item questionnaire with five assessment aspects. The questionnaire results showed that interest and motivation to learn scored

91.67%, ease of use of the virtual lab media scored 91.39%, understanding of reaction rates scored 91.39%, relevance to the STEM approach scored 90.28%, and response to learning scored 92.78%. Based on the data above, the overall average student response was 91.50%, categorized as high/very acceptable. Overall, student responses were in the very good category, indicating that the virtual lab media (PhET simulations) is suitable for use in STEM-based learning.

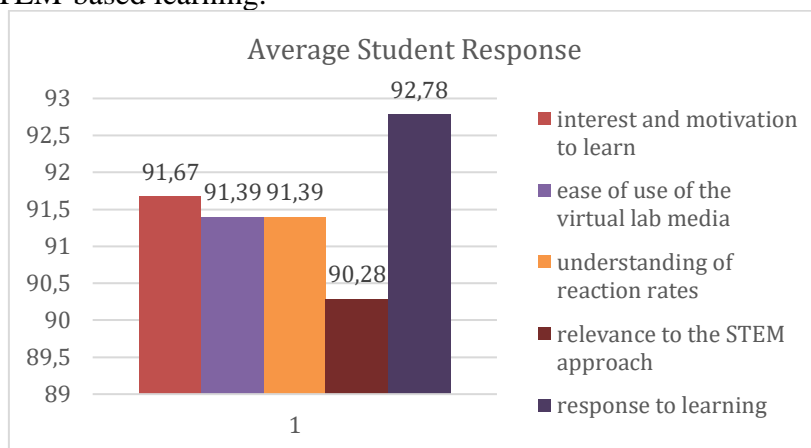


Figure 4. Graph of Average Student Responses

▪ DISCUSSION

The results showed that the use of virtual lab media (PhET simulation) in STEM-based learning significantly improved students' scientific literacy skills on reaction rate topics, as indicated by the t-test results ($t_{\text{count}} 6.807 > t_{\text{table}} 2.045$, $\alpha = 0.05$). This finding confirms that the integration of STEM and virtual lab media is more effective than STEM learning without media. These results are consistent with previous studies, which reported that STEM-based learning supported by technology can enhance students' scientific literacy and conceptual understanding (Dara, 2023; Sabila et al., 2023; Supardi et al., 2025; Drastisianti et al., 2024).

The improvement was also supported by the N-gain results, where the experimental class achieved a high category (0.7742) compared to the control class in the medium category (0.6209). This indicates that virtual lab media facilitates better visualization of abstract concepts and allows students to actively explore experimental variables. In addition, the improvement was more dominant in the competency aspect, showing that students were better able to interpret data, explain scientific phenomena, and draw conclusions, in line with previous findings (Hidayatullah & Mitarlis, 2024).

However, this study is limited to two classes in one school and focuses only on reaction rate material using PhET simulations. Therefore, the results may not be generalized to other contexts or topics. Despite this limitation, this study implies that the integration of STEM-based learning with virtual lab media can be an effective alternative for improving students' scientific literacy, especially in schools with limited laboratory facilities.

▪ CONCLUSION

This study concludes that the use of virtual lab media (PhET simulation) in STEM-based learning has a significant effect on improving students' scientific literacy skills on reaction rate topics. The integration of STEM and virtual lab media provides more effective and meaningful learning experiences compared to STEM learning without

media, particularly in enhancing students' ability to interpret data, explain scientific phenomena, and solve problems.

The findings imply that virtual lab media can be used as an effective alternative learning tool, especially in schools with limited laboratory facilities, to support interactive and student-centered chemistry learning. Therefore, teachers are encouraged to integrate STEM approaches with digital media to improve students' scientific literacy.

For future research, it is recommended to apply this approach to other chemistry topics, involve a larger sample, and explore other aspects of learning outcomes, such as affective and long-term impacts.

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