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Effectiveness of Guided Inquiry Learning With PhET Simulation to Improve Students' Critical Thinking Ability and Understanding of Reaction Rate Concepts

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ABSTRACT

In modern education, fostering critical thinking skills is essential, enabling students to analyze, interpret, and conclude information effectively. This study evaluates the effectiveness of a guided inquiry learning model integrated with PhET simulations in enhancing students' critical thinking abilities and comprehension of reaction rate concepts. The research was quasi-experimental and assigned to experimental and control groups. The study employed pretest and posttest measures using essay questions to assess critical thinking and conceptual understanding. Results from the t-tests demonstrated significant improvements in both critical thinking (count = 2.240 > table = 1.666) and conceptual understanding (count = 3.064 > table = 1.666) for students engaged in guided inquiry with PhET simulations compared to those in traditional discovery learning settings. These findings underscore the potential of guided inquiry supported by simulations to create an interactive and engaging learning environment, promoting deeper cognitive processing and retention. By merging inquiry-based learning with technological tools, educators can enhance student engagement and facilitate a hands-on approach to complex topics, preparing students for more sophisticated academic and real-world problem-solving scenarios. This study suggests that guided inquiry, complemented by PhET simulations, strengthens conceptual foundations and nurtures critical analytical skills necessary for academic success and beyond.

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1. INTRODUCTION

The rapid development of the Fourth Industrial Revolution has redefined educational needs, emphasizing skills such as critical thinking, problem-solving, creativity, innovation, communication, and collaboration. Indonesia faces significant educational challenges, particularly evidenced by consistently low scores in the Program for International Student Assessment (PISA), especially in science and reading. These outcomes indicate gaps in students' critical thinking abilities, a fundamental skill for quality learning and effective participation in a student-centered educational model (Moeti et al., 2016). Chemistry, as a subject, presents unique difficulties for Indonesian students, given its reliance on analytical skills and deep understanding of abstract concepts (Handayanti et al., 2015; Coll & Treagust, 2001; Achor et al., 2021). Students often encounter challenges in topics like reaction rates, where theoretical knowledge and applied problem-solving are required. These challenges are compounded by traditional learning methods that lean heavily on memorization, lack hands-on learning opportunities, and rarely encourage inquiry-based approaches that foster deeper cognitive engagement.

A pressing issue in Indonesian education, especially in the sciences, is the insufficient development of critical thinking skills. Current instructional methods often do not encourage students to analyze, evaluate, and synthesize information effectively, impacting their understanding of complex scientific concepts. Chemistry, which requires a grasp of abstract ideas and mathematical application, often becomes a memorization task, which hinders genuine comprehension and the ability to apply knowledge to real-world situations (Utami et al., 2017). Traditional teaching practices in chemistry focus more on rote learning than on engaging students in

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problem-solving, inquiry, or analytical tasks, all of which are critical for understanding chemistry's dynamic and interconnected concepts.

Consequently, Indonesian students often underperform on assessments that require high-order thinking, such as PISA (Sa'adah et al., 2020). This problem is exacerbated by the lack of technology integration in classrooms, which could provide interactive, visual representations of complex concepts. When students rely on memorization rather than exploration, they miss opportunities to develop essential skills like critical thinking, problem-solving, and transferring knowledge across contexts. Teachers also face limitations in adapting instructional approaches to actively foster critical thinking, as traditional methods do not adequately support individualized learning needs or encourage student autonomy.

Active learning and inquiry-based models must be reconsidered to address these educational challenges, specifically integrating guided inquiry learning with technological tools like PhET simulations. Guided inquiry offers a framework that actively engages students, prompting them to explore, hypothesize, and experiment with scientific content (Blanchard et al., 2010; Bunterm et al., 2014; Bybee, 2014; Almuntasheri et al., 2016). PhET simulations provide a complementary technological tool, making abstract concepts in chemistry more tangible by allowing students to interact with virtual models of scientific phenomena. While guided inquiry and PhET simulations have shown promise in educational contexts, limited research explores their combined impact on student's critical thinking and conceptual understanding, particularly within chemistry education. Previous studies have generally focused on either the independent benefits of inquiry-based learning or the standalone effectiveness of educational technology (Saido et al., 2015; Jia et al., 2017; López-Fernández et al., 2022). However, the combined approach of guided inquiry supported by simulations could offer an enriched learning experience that simultaneously fosters deeper conceptual understanding and critical skills.

Moreover, most existing research on PhET simulations and guided inquiry addresses general science education but does not delve into complex, abstract chemistry topics such as reaction rates. Addressing this gap could yield valuable insights into the synergistic effects of these methods on students' learning outcomes, specifically regarding critical thinking and mastery of complex scientific concepts (Nasution & Surya, 2017).

Advances in educational technology and pedagogy have paved the way for more interactive, student-centered learning approaches (Romine & Sadler, 2016). Research increasingly supports the efficacy of inquiry-based learning models, such as guided inquiry, in enhancing student engagement and critical thinking skills. Guided inquiry is rooted in constructivist theory, which emphasizes that learning is most effective when students actively construct knowledge through exploration and questioning (García González & Veiga Díaz, 2015). Guided inquiry promotes higher-order thinking and a deeper understanding of content by prompting students to ask questions, formulate hypotheses, gather data, and draw conclusions.

PhET simulations, an innovative educational tool, have gained attention for their ability to translate abstract scientific concepts into interactive visual models. These simulations allow students to manipulate variables and observe outcomes in real-time, bridging the gap between theory and practice. In chemistry education, PhET simulations are particularly useful for complex topics like reaction rates, where students can visualize factors such as concentration, temperature, and catalysts, which affect the rate of chemical reactions (Supasorn & Promarak, 2015). By incorporating PhET simulations into guided inquiry, educators can offer students an experiential learning process that reinforces conceptual clarity and critical thinking skills. Studies suggest that when students learn through inquiry supported by visual simulations, they are more likely to understand and retain complex scientific material, leading to improved performance and greater confidence in tackling challenging subjects (Ferty et al., 2019; Salame & Samson, 2019; Trisviati & Lutfi, 2022).

Despite the demonstrated benefits of guided inquiry and PhET simulations, limited research exists on their combined use, particularly in chemistry education. By examining how guided inquiry, supported by PhET simulations, affects critical thinking and conceptual understanding, this study contributes to growing evidence of the potential for technology-enhanced learning environments to support complex cognitive skills.

The primary aim of this study is to evaluate the effectiveness of a guided inquiry learning model, supported by PhET simulations, in improving students' critical thinking abilities and understanding of reaction rate concepts in chemistry. Specifically, this research seeks to determine whether integrating these two methods can enhance students' capacity for critical analysis and deepen their conceptual understanding of reaction rates. Focusing on this interactive and technology-supported approach, the study aims to offer insights into more effective pedagogical strategies for science education, particularly chemistry. Additionally, this research addresses the gap in the existing literature on the combined effects of guided inquiry and simulations, providing

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empirical evidence on how these methods work together to improve learning outcomes in complex scientific domains (Kusumah et al., 2020; Putri & Muhtadi, 2018).

This study contributes to educational theory and practice by highlighting the potential of a constructivist approach to foster critical thinking and conceptual mastery. It also emphasizes the importance of incorporating technological tools, like PhET simulations, into science curricula to make abstract concepts more accessible. Ultimately, the findings aim to inform educators, curriculum developers, and policymakers about effective strategies for enhancing science education and equipping students with essential skills for academic and professional success. By integrating guided inquiry with simulations, this research offers a model that aligns with educational policy goals to prepare students for the demands of a rapidly evolving, technology-driven world.

2. MATERIAL AND METHOD

Research Design

This study employed a quasi-experimental method, as outlined by Campbell and Stanley (2015), selected for its suitability in evaluating the impact of interventions in practical, real-world contexts. A non-equivalent control group design was implemented to assess the effectiveness of the guided inquiry model combined with PhET simulations on students' critical thinking skills and conceptual understanding, as illustrated in **Table 1**. This design effectively supported the study's objectives by enabling controlled comparisons between the experimental and control groups. The approach allowed for a rigorous evaluation of the causal effects of the guided inquiry model with PhET simulation, addressing the primary objective of determining its effectiveness in enhancing students' critical thinking skills and conceptual understanding.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	Y	O_4

Information:

O_1 = experimental group pretest results
O_2 = experimental group posttest results
O_3 = control group pretest results
O_4 = control group posttest results
X = treatment to the experimental group
Y = treatment to the control group

Participants and Sampling

The population in this study comprised 106 class XI students at SMA Negeri 1 Pegandon. Sampling was conducted using a cluster random sampling technique, resulting in the selection of class XI-1 as the experimental group and class XI-5 as the control group, with each class consisting of 36 students aged 18-19 years. The inclusion criteria required participants to be in grade XI, as the curriculum at this level aligns with the study's content, and students possess foundational knowledge relevant to the intervention. No exclusion criteria were applied, as the study sought to evaluate the model's effectiveness across a broad group representing the entire student body.

Instruments and Measurement

This study employed a test-based research instrument, incorporating both a pretest and posttest to assess students' critical thinking abilities and conceptual understanding. Indicators for critical thinking skills in the test were based on the framework proposed by Facione (2015), while conceptual understanding indicators were derived from Kilpatrick et al. (2001). The test questions were structured as essay prompts, with scoring calibrated according to the weight of each question. An instrument is considered valid if it reliably measures the intended constructs. The instrument's validity was tested using the product moment formula as follows.

$$r_{xy} = \frac{N\Sigma xy - \Sigma x\ \Sigma y}{\sqrt{(N\Sigma x^2 - (\Sigma x)^2)\ (N\Sigma y^2 - (\Sigma y)^2)}}$$

Information:

r_{xy} = correlation coefficient
N = number of respondents
Σx = total score of the questions
Σy = total score of questions
Σx^2 = sum of the squared scores of the questions
Σy^2 = the total squared score of the questions

The count value is matched with the product moment table at a significance level of 5%, and if the count> table, then the question item is valid (Dewi, 2018). Test the instrument's reliability using the Cronbach's

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Alpha test (Adamson & Prion, 2013). The research instrument reliability criteria are shown in **Table 2**. The Cronbach's Alpha test formula is as follows.

$$r_i = \frac{k}{(k-1)}\left(1 - \frac{\Sigma s_i^2}{s_t^2}\right)$$

Information:

r_i = Cronbach's Alpha reliability coefficient
k = number of question items in the instrument
Σs_i^2 = total variance in scores for each item
s_t^2 = total variance

Table 2. Student Demographic Data

r_i	Criteria
$0.80 < r_i \leq 1.00$	Very high
$0.60 < r_i \leq 0.80$	High
$0.40 < r_i \leq 0.60$	Enough
$0.20 < r_i \leq 0.40$	Low
$0.00 < r_i \leq 0.20$	Very low

Procedure

The experimental class received instruction through a guided inquiry model, following the orientation sequence, problem formulation, hypothesis generation, data collection, hypothesis testing, and conclusion (Indawati et al., 2021). This guided inquiry sequence was the basis for developing teaching modules for the experimental group. During the first meeting, a pretest was administered to assess students' initial abilities. The second meeting focused on introducing guided inquiry learning to the experimental class. In the third meeting, students presented the results of a group discussion conducted in the previous session. The fourth meeting involved PhET simulation media, allowing students to explore worksheet questions about factors influencing reaction rates. In the fifth meeting, the experimental class presented their group discussion findings. Finally, a posttest was conducted at the sixth meeting to evaluate students' abilities after completing the treatment.

Data Collection

The data collection techniques used in this study are observation and testing. Observation is used to observe the learning process directly, and tests in the form of pretests and posttests are to collect data on student's critical thinking skills and conceptual understanding.

Data Analysis

The data analysis technique used is divided into three stages. The first stage is a preliminary analysis to determine the normality and homogeneity of the population. The second stage is test analysis of the test instruments used to determine the suitability of the instruments to be used for the pretest and posttest. The third stage is the final data analysis to determine whether the guided inquiry model assisted by PhET simulation effectively improves critical thinking skills and understanding of concepts. The scoring technique for pretest and posttest scores for students' critical thinking abilities and understanding of concepts uses the following formula.

$$S = \frac{number\ of\ scores\ answered\ correctly}{maximum\ score} x100$$

Criteria for students' critical thinking, according to Karim (2015), are presented in Table 3, and criteria for understanding concepts, according to Arikunto (2013), are presented in **Table 4**.

Table 3. Critical Thinking Criteria

Score	Criteria
$81.25 < x \leq 100$	Very high
$71.50 < x \leq 81.25$	High
$62.50 < x \leq 71.50$	Enough
$43.75 < x \leq 62.50$	Low
$0.00 < x \leq 43.75$	Very low

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Table 4. Concept Understanding Criteria

Score	Criteria
81 – 100	Very high
61 – 80.99	High
41 – 60.99	Enough
21 – 40.99	Low
0 – 20.99	Very low

The N-gain test determines how much critical thinking skills and understanding of concepts have increased after being given treatment. The formula used is as follows.

$$N\text{-}gain = \frac{posttest\ score - pretest\ score}{ideal\ score - pretest\ score}$$

The N-gain criteria can be written with the achievement levels in **Table 5** (Hake, 2002).

Table 5. N-gain Criteria

N-gain	Criteria
N-gain $\leq$ 0.3	Low
0.7 $\geq$ N-gain $>$ 0.3	Enough
N-gain $>$ 0.7	Tall

To test the hypothesis, use the t-test with the following formula.

$$t = \frac{x1 - x2}{\sqrt{\frac{(n1-1)s_1^2 + (n2-1)s_2^2}{n1+n2-2}\left(\frac{1}{n1} + \frac{1}{n2}\right)}}$$

The criteria for hypothesis testing are if $t_{count} < t_{table}$, then Ho is accepted, and Ha is rejected; if tcount > ttable, then Ho is rejected, and Ha is accepted (Sugiono, 2013).

3. RESULTS

Descriptive Statistics and Demographic Data

In the initial research stage, a preliminary analysis determines the initial state of the population used to determine the sample. This stage includes a normality test and a population homogeneity test. The population of this study consisted of three classes. Population data must be ensured to be normally distributed before sampling using cluster random sampling. Based on the population normality test calculations obtained in **Table 6**, it is known that χ^2_{table} = 11.07. The population consists of three classes, and each class produces $\chi^2_{count} < \chi^2_{tabel}$ at a significance level of 5%, so it can be concluded that the population is normally distributed. Homogeneity analysis uses the Bartlett test with the condition that Ho is accepted if $\chi^2_{count} < \chi^2_{tabel}$, then the population has homogeneous criteria. Based on the calculations obtained, χ^2_{count} = 1.88 at a significance level of 5% and χ^2_{tabel} = 5.99. This result shows that $\chi^2_{count} < \chi^2_{tabel}$ so that the population is declared homogeneous. The normality and homogeneity analysis results produce normal and homogeneous data to fulfill the requirements for cluster random sampling. The samples used in this research were class XI-1 as the experimental class and XI-5 as the control class.

Table 6. Population Normality Test Result

Class	χ^2_{count}	χ^2_{table}	Conclusion
XI-1	7.38	11.07	Normal
XI-3	9.25	11.07	Normal
XI-5	7.57	11.07	Normal

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Instrument Validation and Reliability

The research instrument consisted of essay questions. To test the validity of these questions, 12 essay items were trialed with 20 students from class XII MIPA 4. At a 5% significance level, the critical value for r (table) was 0.05. An item was considered valid if count> table. According to **Table 7**, ten of the 12 questions tested were found to be valid, while 2 were invalid and therefore excluded. The reliability analysis yielded an r-value of 0.62, indicating that the items were reliable. The questions were designed with varying levels of difficulty, and the analysis identified 2 difficult, 8 medium, and 2 easy questions. Further analysis of the items' discrimination power showed that 10 questions had satisfactory discrimination, while 2 questions were discarded for having poor discrimination. Thus, a total of 10 essay questions met the criteria for inclusion as research instruments.

Table 7. Question Validation Result

Criteria	Question Number	Total
Valid	3, 4, 5, 6, 7, 8, 9, 10, 11, 12	10
Invalid	1, 2	2

Instrument Validation and Reliability

The pretest and posttest results for students' critical thinking skills are displayed in **Table 8**. The average scores for critical thinking in the experimental class were higher than those in the control class. Specifically, the average pretest score for critical thinking on reaction rate material was 27.54 in the experimental class and 27.51 in the control class. The experimental class received instruction through a guided inquiry model supported by PhET simulations, while the control class was taught using a discovery learning model. The learning process proceeded smoothly, with students showing high enthusiasm for learning. During the guided inquiry sessions, students actively formulated problems, generated hypotheses, collected data, tested hypotheses, and drew conclusions.

Table 8. Data on Critical Thinking Pretest and Postest Results

Score	Experimen Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
Average	27.54	77.24	27.51	70.44
Maximum	38.10	88.10	36.90	91.67
Minimum	21.43	52.38	16.67	22.62

As shown in **Table 9**, the average pretest and posttest scores for conceptual understanding in the experimental class are higher than those in the control class. Additionally, Table 11 presents the scores for conceptual understanding broken down by each specific indicator.

Table 9. Result of Pretest and Posttest Understanding of Concept

Score	Experimental Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
Average	30.52	79.99	27.79	69.95
Maximum	38.63	92.05	35.22	89.77
Minimum	23.86	45.45	14.77	28.40

Effect of Guided Inquiry on Critical Thinking Components and Concept Understanding Indicators

The average critical thinking ability value for each indicator can be seen in **Table 10**. **Table 11** shows the value of concept understanding based on each indicator.

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Table 10. Result of Analysis of Critical Thinking Indicators

Critical Thinking Indicators	Experimental Class			Control Class		
	Pretest	Posttest	Enhancement	Pretest	Posttest	Enhancement
Interpretation	1.04	90.28	89.24	1.04	63.88	62.84
Analysis	35.07	86.29	51.22	31.25	75.17	43.92
Evaluation	3.47	80.79	77.32	5.32	62.26	56.94
Inference	53.70	81.37	27.67	57.52	82.17	24.65
Explanation	15.04	63.19	48.15	13.42	61.92	48.50

Table 11. Result of Analysis of Concept Understanding Indicators

Indicator of concept understanding	Experimental Class			Control Class		
	Pretest	Posttest	Enhancement	Pretest	Posttest	Enhancement
Restate the concepts	33.79	83.21	49.42	32.98	76.15	46.17
Classify objects	30.55	73.95	43.40	28.12	78.47	50.35
Apply concepts in an algorithm	25.00	72.45	47.45	23.84	59.02	35.18
Provide examples of concepts	57.63	70.13	12.50	38.88	65.97	27.09
Present concepts in the form of representations	34.37	83.33	48.96	35.06	64.23	29.17
Associate various concepts	28.58	84.95	56.37	21.29	72.45	51.16
Develop necessary and sufficient conditions.	29.51	80.20	50.69	23.95	61.80	37.85

Based on pretest and posttest scores, the N-gain test was administered to measure the improvement in students' critical thinking skills and conceptual understanding. The results of the N-gain test are displayed in **Figure 1**.

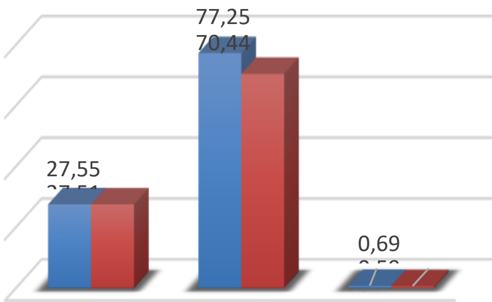

Figure 1. Graph of N-Gain Critical Thinking

As shown in **Figure 1**, the average pretest score for the experimental class was 27.55, which increased to 77.25 in the posttest, resulting in an N-gain of 0.69. In comparison, the control class had an average pretest score of 27.51 and a posttest score of 70.44, yielding an N-gain of 0.59. The improvement in critical thinking skills between the experimental and control classes indicates that students who received instruction through the guided inquiry model assisted by PhET simulation achieved a higher average N-gain than those in the control class. This finding supports the effectiveness of the guided inquiry model with PhET simulations in enhancing students' critical thinking skills more effectively than the traditional instructional approach used in the control

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group. The average pretest and posttest scores for each critical thinking indicator are shown in **Figure 2**.

The N-gain graph for each critical thinking indicator demonstrates an increase in students' critical thinking abilities, with the N-gain values for each indicator being higher in the experimental class than in the control class. This indicates that the experimental class, which utilized the guided inquiry model supported by PhET simulations, experienced a greater improvement in critical thinking skills compared to the control class.

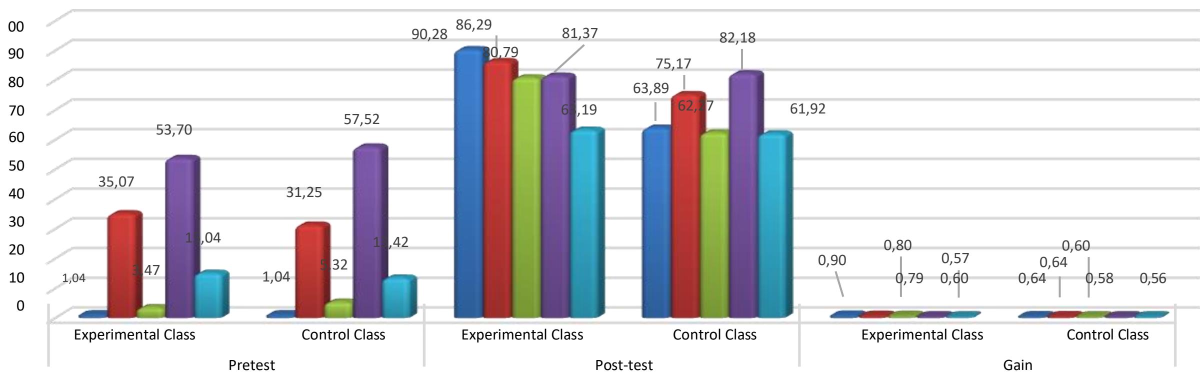

Figure 2. N-Gain Graph of Critical Thinking Indicators

Figure 3 illustrates the improvement in conceptual understanding between the experimental and control classes, revealing that the average N-gain value for the experimental class is higher than that of the control class. Additionally, **Figure 4** presents the average pretest and posttest scores for each indicator of students' conceptual understanding.

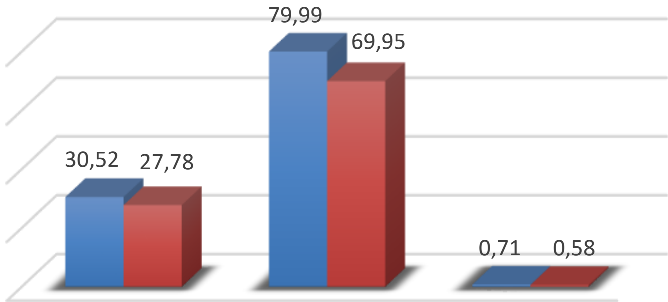

Figure 3. Graph of N-gain of Concept Understanding

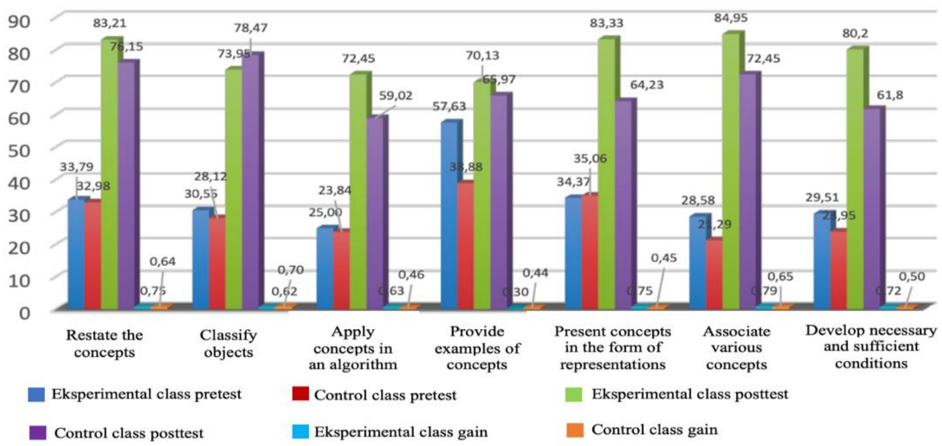

Figure 4. Graph of N-gain Indicator of Concept Understanding

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The N-gain graph for the conceptual understanding indicators demonstrates increased students' understanding. N-gain values for each indicator show higher scores in the experimental class than in the control class. The experimental class, which utilized the guided inquiry model supported by PhET simulations, experienced a greater improvement in conceptual understanding compared to the control group. According to the critical thinking t-test results displayed in **Table 12**, count> table at a 5% significance level, indicating that the guided inquiry learning model assisted by PhET simulations effectively enhances students' critical thinking skills.

Table 12. Results of Critical Thinking t-test Analysis

Hypothesis 1		
	Experimental Class	**Control Class**
Total (Σ)	2780.89	2535.71
Number of subjects (N)	36	36
Average score	77.24	70.43
Standard deviation (S)	11.31	14.41
Variance (S^2)	127.99	207.93
table	1.66	
t_{count}	2.24	

Table 13 indicates that tcount>ttable at a 5% significance level for conceptual understanding. This result confirms that the guided inquiry learning model, supported by PhET simulations, effectively enhances students' conceptual understanding.

Table 13. Results of t-test Analysis Concept Understanding

Hypothesis 2		
	Experimental Class	Control Class
Total (Σ)	2879.54	2517.75
Number of subjects (N)	36	36
Average score	79.98	69.93
Standard deviation (S)	12.50	15.32
Variance (S^2)	156.33	234.78
table	1.66	
t_{count}	3.06	

4. Discussion

Guided inquiry can support students' critical thinking processes. As an application of constructivist learning theory, it emphasizes scientific investigation and exploration, making it particularly well-suited for science education. Through guided inquiry, students engage in active learning, constructing knowledge by examining, questioning, and investigating scientific concepts, thus developing critical thinking skills essential for deeper understanding and problem-solving in science.

Effectiveness of Guided Inquiry in Critical Thinking Development

Guided inquiry fosters critical thinking skills through scientific investigation and active participation, aligning with constructivist learning theory (García González & Veiga Díaz, 2015). It promotes collaboration and higher-order thinking (Triwiyanti, 2023; Priyambodo, 2023) and improves critical thinking and language skills through real-life engagement, unlike traditional discovery learning, which often lacks diverse media and structured guidance (Prastyaningrum et al., 2023; Sudarisman, 2015). Technology and scaffolding enhance collaboration, creativity, and communication (Jaswal & Behera, 2023; Xu et al., 2023). During group discussions on reaction orders, the experimental class utilized PhET simulations for activities, engaging enthusiastically by

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asking questions and exploring the media, which deepened their understanding of factors affecting reaction rates.

The posttest results showed that the experimental class achieved an average score of 77.24, compared to 70.44 in the control class. The N-gain test indicated improvement in both groups, with the experimental class scoring 0.69 and the control class 0.59, within the "medium" category. However, the higher score of the experimental class highlights the greater effectiveness of the guided inquiry model. A detailed analysis of critical thinking indicators is crucial to understanding the impact of this skill development on learning outcomes.

The interpretation indicator, which measures students' ability to articulate responses clearly, showed significant improvement in the experimental class. The average pretest and posttest scores increased from 1.04 to 90.28, achieving a "very high" level of critical thinking with an N-gain of 89.24. In contrast, the control class scores rose from 1.04 to 63.88, reflecting a medium-level improvement with an N-gain of 62.84. The superior performance of the experimental class can be attributed to the guided inquiry model, which fosters independent learning, critical thinking, and active engagement (Ural, 2016; Yunianti et al., 2019; Haryadi & Pujiastuti, 2020). This approach helps students bridge theoretical concepts with practical applications, enhancing their understanding and learning outcomes (Solikah & Novita, 2022; Santoso & Hidayat, 2021; Indawati et al., 2023). The results demonstrate the effectiveness of the guided inquiry model in promoting deeper learning and equipping students with essential skills for academic success and real-world problem-solving.

The analysis indicator measures students' ability to identify steps for solving problems. The experimental class showed an average pretest and posttest score increase from 35.07 to 86.29 (gain: 51.22, "low"), while the control class improved from 31.25 to 75.17 (gain: 43.92, "low"). The experimental class's higher improvement is attributed to the guided inquiry model, which promotes systematic thinking, critical evaluation, and active learning. Research highlights that guided inquiry enhances critical thinking by fostering independence and active participation (Aswirna, 2024; Nurhayati et al., 2021). This approach improves academic performance and equips students with essential problem-solving skills through its structured and engaging framework (Triwiyanti, 2023; Haedi, 2022).

The evaluation indicator measures students' ability to articulate problem-solving processes. In the experimental class, the average pretest and posttest scores rose from 3.47 to 80.79, reflecting a "high" improvement of 77.32, compared to the control class, which improved from 5.32 to 62.26, a "low" gain of 56.94. This disparity highlights the effectiveness of the guided inquiry model in fostering a systematic approach to thinking and problem-solving. The experimental class's higher scores demonstrate their ability to connect real-life events to academic topics and integrate credible sources, facilitated by reflective thinking, a core feature of the guided inquiry model (Kozikoğlu & Tunç, 2020; Basri et al., 2019). This reflective practice helps students analyze cause-effect relationships, critically assess their understanding, and maximize insights from observations (Hong & Kim, 2016). Research by Basri et al. (2019) and Jeong (2015) emphasizes that structured problem-solving and reflection improve reasoning and the ability to connect experiences with learning, which is essential for excelling in the evaluation and practical application of knowledge (Basri et al., 2019; Jeong, 2015; Agustiani, 2022).

The inference indicator, which measures the ability to draw logical conclusions, showed small gains in both classes, with the experimental class increasing from 53.70 to 81.37 (27.67 gain, "very low") and the control class improving from 57.52 to 82.17 (24.65 gain, "deficient"). These results suggest that students in both groups already possessed strong foundational inference skills essential for problem-solving. In contrast, the explanation indicator, which assesses the ability to articulate conclusions and provide reasoning, showed a more significant impact from the intervention. The experimental class's scores rose from 15.04 to 63.19, a gain of 48.15 ("low"), while the control class increased from 13.42 to 61.92, with a similar gain of 48.50. Despite comparable improvements, the experimental class demonstrated slightly better proficiency in explanatory skills. These findings underscore the importance of targeted teaching strategies, such as guided inquiry, in enhancing specific cognitive skills (Suharyat, 2023; Khakiki, 2023; Nehru et al., 2020).

The five critical thinking indicators analysis revealed that the guided inquiry model, supported by PhET simulations, significantly improved students' interpretation and evaluation skills. This aligns with findings from Arif and Asikhin (2022), who demonstrated the model's effectiveness in enhancing interpretation, and Salame and Makki (2021), who highlighted PhET simulations' role in fostering evaluative thinking. Azizah and Nasrudin (2022) reported a 77.91% improvement in problem-solving skills through structured approaches, while Nurhawa et al. (2022) emphasized the effectiveness of inquiry-based methods in tackling real-world problems. In

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conclusion, the guided inquiry model, combined with PhET simulations, equips students with critical tools for understanding and solving complex problems, fostering deeper critical thinking.

Statistical t-tests confirmed that the guided inquiry learning model, supported by PhET simulations, significantly enhances students' critical thinking skills. The experimental class showed notable improvement, with only 9 out of 36 students scoring below the minimum completeness criterion of 75, compared to 17 students in the control class. These findings align with existing research supporting guided inquiry as an effective pedagogical approach for fostering critical thinking. PhET simulations further enhance this model by enabling students to visualize complex concepts and engage in interactive learning. Studies, such as Salame and Makki (2021), demonstrate that integrating PhET simulations improves conceptual understanding and develops higher-order thinking skills by encouraging students to analyze, evaluate, and apply their knowledge through active engagement.

The significant performance gap between the experimental and control classes underscores the importance of instructional design in fostering critical thinking. Azizah and Nasrudin (2022) highlighted that structured approaches like guided inquiry improves problem-solving and critical thinking skills, especially in chemistry education. In this study, the guided inquiry model, supported by PhET simulations, provided a framework for deeper student engagement and enhanced critical thinking. Statistical evidence confirms that guided inquiry outperforms discovery learning in developing these skills, emphasizing the need for instructional strategies that promote students' critical thinking and problem-solving abilities.

Effectiveness of Guided Inquiry in Conceptual Understanding

Students' critical thinking skills, measured through pretest and posttest scores, showed significant improvement in the experimental class, with scores rising from 30.52 to 79.99, placing them in the "high" category. In contrast, the control class improved from 27.79 to 69.95, categorized as "medium," demonstrating stronger conceptual understanding in the experimental group. The concept restatement indicator, measuring the ability to rephrase concepts, also favored the experimental class with a gain of 49.42 compared to 43.17 in the control group. This highlights the effectiveness of the guided inquiry model with PhET simulations in fostering deeper engagement and comprehension. Research supports these findings, with Salame and Makki (2021) noting that PhET simulations enhance students' ability to explain abstract concepts by bridging theoretical and practical knowledge through active engagement. Similarly, Ismalia et al. (2022) and Cavadas and Aboim (2020) emphasized that simulations boost higher-order thinking skills, motivation, and active learning, enabling better articulation of concepts. The experimental class's superior performance demonstrates the guided inquiry model's ability, combined with PhET simulations, to improve comprehension, encourage active participation, and achieve better learning outcomes.

The indicator for classifying objects evaluates students' ability to categorize or identify properties based on their concepts. In the experimental class, the average pretest and posttest scores increased from 30.55 to 73.97, with a gain of 43.42, categorized as "medium." The control class showed a higher improvement, from 28.12 to 78.47, with a gain of 50.35, falling into the "sufficient" category. This suggests that the control class outperformed the experimental class in classification tasks, likely due to the discovery learning model, which emphasizes self-directed exploration and hands-on investigation, enhancing students' memory and classification skills (Iftitah, 2023; Nurussaniah & Sari, 2019). While discovery learning provides immediate advantages in classification, inquiry-based methods like the guided inquiry model in the experimental class are better suited for fostering critical thinking skills necessary for deeper cognitive development and knowledge application (Himmatussolihah et al., 2020). Thus, although the control class excelled in classification tasks, the guided inquiry model's emphasis on critical thinking may yield superior results in addressing more complex learning objectives.

The algorithm application indicator evaluates students' ability to solve problems using established procedures. The experimental class showed a significant improvement, with pretest and posttest scores rising from 25.00 to 72.45 (gain: 47.45, "medium"), compared to the control class, which increased from 23.84 to 59.02 (gain: 35.18, "low"). The higher performance in the experimental class can be attributed to the guided inquiry model, which emphasizes active investigation and understanding of concepts, enabling students to select and apply appropriate problem-solving procedures effectively. Research by Santoso and Hidayat (2021) supports this, highlighting that guided inquiry enhances critical thinking skills, particularly in applying algorithms. By fostering active exploration and critical engagement with learning material, the guided inquiry model equips students with the skills to navigate complex problems and implement suitable problem-solving strategies, as reflected in the notable score difference between the experimental and control classes.

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
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The indicator for providing examples of concepts evaluates students' ability to apply reaction rates in everyday life. The experimental class improved from 57.63 to 70.13 ("very low"), while the control class increased from 38.88 to 65.97 ("low"), with the experimental class excelling in connecting reaction rates to real-life scenarios. However, the modest gains in the experimental class, despite higher posttest scores, suggest challenges in fully grasping the concept due to the exploratory nature of the guided inquiry model. In contrast, the control class's higher gains may reflect the benefits of structured examples in traditional methods, which aid in conceptual understanding by scaffolding new knowledge with prior learning (Wafiq et al., 2022; Widarti et al., 2022). Suciati et al. (2018) emphasized that scientific approaches enhance critical thinking, essential for understanding and applying concepts like reaction rates. These findings suggest a need for refined instructional strategies incorporating clear, relatable examples to enhance comprehension and application.

The indicator for presenting concepts through chemical representations evaluates students' ability to use images, symbols, equations, and molecular structures to express reaction rates. The experimental class improved significantly, with scores increasing from 34.37 to 83.33 (gain: 48.96, "medium"), compared to the control class, which improved from 35.06 to 64.23 (gain: 29.17, "low"). The experimental class's higher scores are attributed to hands-on activities in the guided inquiry model, which promotes active learning, critical thinking, and more profound comprehension of complex concepts like reaction rates. This approach effectively equips students with the skills to represent and navigate chemical concepts more accurately, highlighting the model's superiority over traditional methods.

The indicator for linking various concepts evaluates students' ability to apply concepts in problem-solving. The experimental class showed a significant improvement, with scores rising from 28.58 to 84.95 (gain: 56.37, "medium"), compared to the control class, which increased from 21.29 to 72.45 (gain: 51.15, "medium"). The guided inquiry model's emphasis on active engagement and critical thinking likely contributed to the experimental class's superior performance, enabling students to deeply explore and apply concepts in various contexts, enhancing problem-solving skills. In contrast, the discovery learning model in the control class supports concept retention but does not fully foster application skills. Research by Mintii (2023), Hidayah (2015), and Kasimatis et al. (2018) highlights the importance of inquiry-based learning in promoting critical thinking and linking concepts across disciplines, such as science and engineering, to tackle complex problems. The guided inquiry model's structured framework effectively fosters deeper understanding and practical application of knowledge, as demonstrated by the experimental class's results.

The indicator for developing necessary and sufficient conditions evaluates students' ability to solve problems using known procedures. The experimental class improved significantly, with scores rising from 29.51 to 80.20 (gain: 50.69, "medium"), compared to the control class, which increased from 23.95 to 61.80 (gain: 37.85, "low"). The guided inquiry model, emphasizing active learning and critical thinking, enabled the experimental class to engage deeply with the material, fostering an understanding of the conditions needed for problem-solving. In contrast, the control class struggled with fundamental concepts, limiting their ability to apply procedures effectively. Research by Widarti et al. (2022) and Davidowitz et al. (2010) highlights that conceptual understanding is crucial for applying knowledge in new contexts, a strength of the guided inquiry model. This approach's structured exploration and hands-on activities bridge theory and practice, underscoring its effectiveness in developing critical thinking and problem-solving skills.

Based on the seven indicators of conceptual understanding discussed, it was found that the guided inquiry model assisted by PhET simulations had the most significant impact on improving the indicator of linking various concepts. In guided inquiry learning, students are directed to engage in hands-on activities, encouraging them to connect different material concepts. Additionally, PhET simulations aid students in visualizing abstract concepts related to reaction rates, making these concepts more accessible and easier to understand.

Statistical tests using the t-test confirmed that the guided inquiry learning model, supported by PhET simulations, effectively enhances students' conceptual understanding. Differences in conceptual understanding were evident between the experimental and control classes. Only eight of the experimental class of 36 students did not meet the minimum completeness standard of 75. In contrast, the control class, with 36 students, had 17 students scoring below the minimum completeness criteria.

Role of PhET Simulations In Enhancing Critical Thinking and Conceptual Understanding

PhET simulations provide an interactive experience that makes abstract scientific concepts more accessible by allowing students to visualize and manipulate variables in a virtual environment. These simulations offer immediate feedback, helping students understand cause-and-effect relationships. Integrated into a guided

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inquiry model, they enable self-paced exploration of complex phenomena, fostering deeper engagement and comprehension. This active learning approach empowers students to construct knowledge actively, reinforcing conceptual clarity and promoting meaningful, lasting learning.

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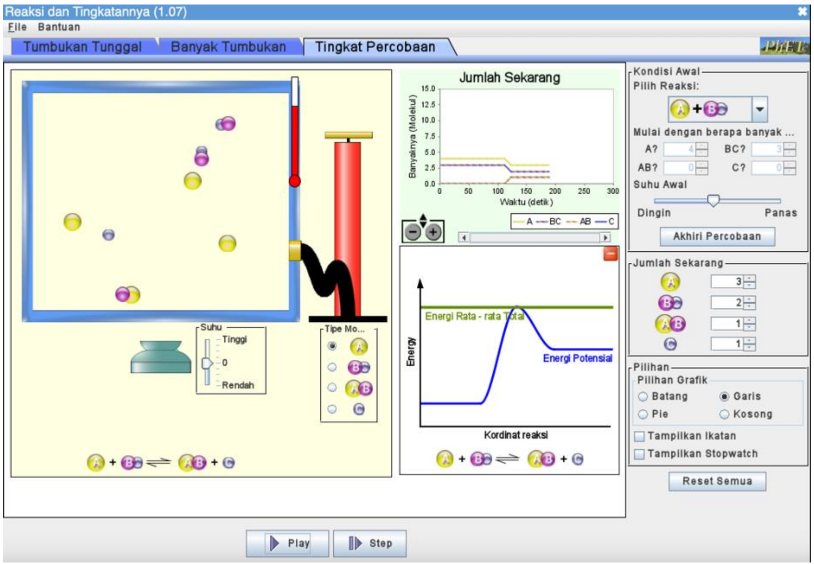

Figure 5. Example of Using PhET in Reaction Rate Simulation

Comparative Insights: Guided Inquiry vs. Traditional Methods

Guided inquiry models offer a student-centered alternative to traditional lecture-based teaching methods, fostering critical thinking and deeper comprehension of scientific concepts. Unlike traditional methods, where students passively receive information and engagement is often limited, guided inquiry encourages active participation through exploration, investigation, and conclusion formation. This hands-on, problem-solving approach enhances retention and provides a more meaningful understanding of scientific concepts, creating a richer and more engaging learning experience.

Research comparing guided inquiry and traditional methods has demonstrated that students taught through guided inquiry exhibit significantly higher levels of critical thinking (Sari & Muchlis, 2022). Students using guided inquiry with interactive tools like PhET simulations are better equipped to analyze variables, make connections between theoretical concepts and practical applications, and apply their knowledge to new situations. This method enhances student engagement and encourages learners to reason through challenging content, moving beyond rote memorization to build a deeper conceptual understanding.

Educational Implications for Science Curriculum

Integrating guided inquiry with PhET simulations can transform science curricula by providing an engaging, hands-on approach that fosters active learning, critical thinking, and a deeper understanding of scientific concepts. This combination allows students to explore phenomena interactively, supports diverse learning styles, and enhances scientific reasoning, problem-solving, and collaboration skills. It also encourages teachers to adopt a more facilitative role, tailoring support to individual student needs. Aligned with education policy goals for a technology-driven world, this model equips students with critical skills for future challenges and holds significant potential to improve science education across diverse settings.

Limitations and Directions for Future Research

While this study offers valuable insights, several limitations should be acknowledged to contextualize its findings. A primary limitation is the sample size, which may restrict the generalizability of the results. A larger

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and more diverse sample could help validate the findings across a broader population. The study's focus on a specific educational context may limit its applicability in other environments or settings. Future research should aim to expand the sample size and diversify study settings to assess the robustness and applicability of these conclusions across different educational landscapes.

5. CONCLUSION

This study demonstrates that integrating guided inquiry with PhET simulations significantly enhances students' critical thinking and conceptual understanding of reaction rates. The findings suggest that this approach fosters deeper cognitive engagement, enabling students to grasp challenging topics more effectively than through traditional teaching methods. Contributing to educational theory, the study reinforces constructivist learning principles by highlighting the benefits of active learning environments where students build knowledge through exploration. It also underscores the value of technology in science education, showing that tools like PhET simulations can facilitate experiential learning by bridging theoretical concepts with practical applications. These findings offer educators and curriculum developers practical insights into incorporating guided inquiry and technology-based simulations to boost student engagement and understanding. Implementing guided inquiry activities with PhET simulations can empower students to actively participate in their learning actively, enhance critical thinking, and improve retention of complex scientific concepts.

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