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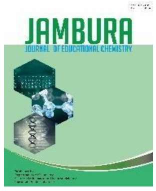

Effects of POGIL and Verification Approaches on Students' Cognitive Achievement in Reaction Rate: The Moderating Role of Scientific Reasoning

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Abstract

This study examined the effectiveness of the Process Oriented Guided Inquiry Learning (POGIL) approach in improving students' conceptual understanding of reaction-rate concepts and investigated whether scientific reasoning skills moderate the effect of instructional model in a 2×2 factorial design. Forty-four tenth-grade science students from two intact classes were matched and categorized into high and low scientific reasoning groups. Conceptual understanding was measured using a two-tier diagnostic test, and assumptions for Two-Way ANOVA were verified before analysis. Results indicated a significant main effect of instructional model, with POGIL achieving higher scores than verification-based instruction ($F = 20.385$, $p < 0.001$, $\eta^2 = 0.29$). Scientific reasoning also significantly influenced outcomes ($F = 7.328$, $p = 0.010$, $\eta^2 = 0.10$). The interaction between instructional model and reasoning was not statistically significant ($F = 2.559$, $p = 0.118$), indicating that the interaction effect was not statistically significant in this sample. POGIL is theoretically expected to support integration of macroscopic, submicroscopic, and symbolic representations through guided inquiry and collaborative scaffolding. Limitations include the small sample size and quasi-experimental design. These findings highlight the potential of guided inquiry-oriented instruction to enhance conceptual understanding while emphasizing the role of reasoning skills, with cautious interpretation of non-significant interactions.

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1. INTRODUCTION

Understanding reaction rate is a central learning objective in high school chemistry. Mastery of this topic requires students to coordinate macroscopic observations, submicroscopic particle interactions, and symbolic representations such as equations and graphs (Rodiatul & Alizar, 2024; Zhang & Jiang, 2026). Prior studies consistently show that students struggle to integrate these three representational levels, leading to fragmented and often incorrect conceptions of reaction rate phenomena (Cakmakci, 2010; Kolomuç & Tekin, 2011). These representational challenges are particularly evident in concepts involving abstract ideas such as effective collisions, activated complexes, and energy distributions—concepts that require advanced reasoning and the ability to mentally manipulate nonobservable entities.

A body of research suggests that such representational integration is fundamentally tied to students' scientific reasoning ability. Scientific reasoning involves proportional reasoning, controlling variables, correlational thinking, probabilistic reasoning, and hypothetico–deductive reasoning (Lawson, 2004; Lawson et al., 2000). These reasoning patterns are essential for interpreting kinetic data, analyzing particle-level explanations, and constructing conceptual understanding of reaction rate mechanisms. Empirical evidence indicates that scientific reasoning strongly

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predicts students' conceptual understanding and achievement across science domains (Nnorom, 2013; Oloyede, 2012; Supriadi et al., 2022). In the Indonesian context, research also shows that many students still demonstrate limited scientific reasoning and argumentation skills, which constrains their ability to engage with abstract and multilevel chemical concepts, such as reaction rate mechanisms (Putri & Rohaeti, 2025).

Given these cognitive demands, inquiry-based learning—particularly Process Oriented Guided Inquiry Learning (POGIL)—has been widely recommended to promote deeper conceptual development and scientific reasoning. POGIL structures learning through phases of orientation, exploration, concept construction, and application, providing intellectual scaffolding that supports students in building understanding through evidence-based reasoning (Bao et al., 2009; Hanson, 2006). Prior studies have demonstrated the effectiveness of POGIL for improving conceptual understanding in chemistry (Solehuddin et al., 2025; Thoron & Myers, 2012). However, instructional practices in Indonesian classrooms remain dominated by verification-oriented approaches, which emphasize confirming known concepts rather than constructing new understanding.

Although the positive effects of POGIL and the importance of scientific reasoning have been widely studied, little research has examined how scientific reasoning interacts with instructional approaches. Most existing studies conceptualize scientific reasoning as a predictor of learning outcomes or as an outcome of instructional interventions, but rarely as a moderator in experimental designs. This represents a critical gap, because theoretical frameworks such as the Aptitude–Treatment Interaction (ATI) (McLeod et al., 1978; Snow, 1989) argue that students' cognitive characteristics determine the extent to which they benefit from particular instructional methods. From an ATI perspective, students with high scientific reasoning are expected to benefit more from POGIL, which demands active engagement, hypothesis testing, and representational integration. Conversely, students with low scientific reasoning may perform better under verification-oriented instruction, which provides more structured guidance and reduces cognitive complexity.

Therefore, this study investigates the effects of POGIL and verification approaches on students' cognitive learning outcomes in reaction rate learning and examines whether scientific reasoning moderates the relationship between instructional models and learning outcomes. Grounded in the ATI framework, this study expects:

(1) a main effect of instructional model, with POGIL outperforming verification;
(2) a main effect of scientific reasoning level; and
(3) a significant interaction, in which students with high scientific reasoning benefit more from POGIL than from verification learning.

2. METHOD

2.1 Research Design

This study employed a quasi-experimental 2×2 factorial design involving two intact Grade X science classes, one taught using the POGIL model and the other through a verification approach. Because intact classes were used without individual random assignment, the study is classified as a quasi-experiment, acknowledging potential threats to internal validity such as pre-existing inter-class differences (Fraenkel et al., 2022).

Prior to treatment, all students completed the Lawson Classroom Test of Scientific Reasoning (LCTSR). Based on these scores, students from Class X MIPA 2 and X MIPA 3 were paired through a score-matching procedure to minimize initial group differences. A total of 22 matched pairs were formed, producing 44 participants who were subsequently categorized into high and low scientific reasoning skill (SRS) groups using the class mean as the cutoff. The independent variable was the instructional model (POGIL vs. verification), the dependent variable was students' conceptual understanding of reaction rates, and the moderating variable was SRS.

2.2 Population and Sample

The population comprised all Grade X science students at SMAN 8 Malang. Two intact classes, X MIPA 2 and X MIPA 3, were selected using cluster random sampling. From these classes, 44 students were included in the sample following the matching procedure described earlier. Students were then assigned to high- and low-SRS groups based on Lawson's classification framework (Lawson, 2004), resulting in proportional distribution across the 2×2 factorial structure.

2.3 Research Instruments

a. Lesson Plans and Learning Scenarios.

Lesson plans for both instructional models were developed according to their respective syntactic structures. Three expert validators evaluated conceptual representation, clarity, and alignment with learning objectives. Revisions were made based on the feedback to ensure that each instrument reflected the essential characteristics of the instructional model.

b. Reaction-Rate Conceptual Understanding Test.

Students' conceptual understanding was measured using a 17-item two-tier diagnostic test consisting of a content tier and a justification tier. Two-tier diagnostic tests are recommended for detecting misconceptions and improving construct validity (Adodo, 2013; Treagust, 2012).

c. Scientific Reasoning Skills Test.

Scientific reasoning skills were assessed using the multiple-choice version of the LCTSR (Lawson et al., 2000) translated into Indonesian. The instrument measures proportional, correlational, and probabilistic reasoning, conservation, and control of variables (Thoron & Myers, 2012).

d. Validity and Reliability Testing

Content validity was evaluated by three expert validators. Item relevance, conceptual accuracy, and linguistic clarity were assessed using Aiken's V. Following Landis & Koch, (1977) criteria, all instruments demonstrated very high content validity, with V values ranging from 0.95 to 0.97.

Reliability testing was conducted using pilot data from Grade XI students at SMAN 1 Blitar. Cronbach's Alpha coefficients were 0.76 for LCTSR and 0.70 for the reaction-rate conceptual test. Although these values are marginal, they remain acceptable for exploratory and classroom-based research (Fraenkel et al., 2022). Moderate reliability is also commonly observed in two-tier diagnostic tests due to the cognitive demands of the justification tier (Treagust, 2012). High content validity values further support the adequacy of the instruments.

2.4 Data Collection Procedures

Data collection was conducted in three stages.The preparation stage involved identifying core competencies, developing lesson plans and assessment instruments, validating all instruments through expert review, and piloting the LCTSR and two-tier test. The implementation stage included administering the LCTSR pretest, conducting POGIL-based instruction in the experimental class and verification-based instruction in the control class, and administering the posttest.The finalization stage consisted of scoring and categorizing SRS levels, organizing data, and preparing datasets for statistical analysis.

2.5 Data Analysis

Assumption testing included the Shapiro–Wilk test for normality and Levene's test for homogeneity. Two-way ANOVA was used to examine the main effects of instructional model and SRS as well as the interaction between the two factors (Fraenkel et al., 2022)

3. RESULT AND DISCUSSION

3.1. Result

a. Normality and Homogeneity Tests

The results of the Shapiro–Wilk test showed that the distribution of students' reaction-rate scores in both classes met the normality assumption. The experimental class (POGIL) obtained $p = 0.491$, while the control class (verification) obtained $p = 0.751$, indicating that both groups were normally distributed ($p > 0.05$). The Levene's test also indicated homogeneous variances across groups with $p = 0.382$. These results confirm that the data fulfilled the assumptions required for conducting a two-way ANOVA.

b. Main Effect of Instructional Model

The two-way ANOVA revealed a significant main effect of the instructional model on students' conceptual understanding of reaction rate, $F(1, 40) = 20.385$, $p < 0.001$. The descriptive statistics show that students taught using POGIL achieved a higher mean score ($M = 83.82$) compared with students taught using the verification approach ($M = 70.18$). This indicates that POGIL was more effective in enhancing students' understanding of reaction-rate concepts than the verification model.

c. Main Effect of Scientific Reasoning Skill (SRS)

A significant main effect was also found for scientific reasoning skill, $F(1, 40) = 7.328$, $p = 0.010$. Students with high SRS attained higher mean scores ($M = 81.33$) than students with low SRS ($M = 73.40$), regardless of the instructional model. These results indicate that scientific reasoning skill contributes meaningfully to students' achievement in understanding reaction-rate concepts.

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d. Interaction Effect Between Instructional Model and SRS

The interaction between instructional model and scientific reasoning skill was not statistically significant, $F(1, 40) = 2.559$, $p = 0.118$. This finding suggests that the effectiveness of POGIL does not depend on students' SRS levels. In both SRS categories, students taught through POGIL demonstrated higher conceptual understanding scores than those taught through the verification approach.

The descriptive data support this pattern. In the POGIL class, students with high SRS achieved a mean score of 85.59, while those with low SRS scored 82.35. In comparison, the verification class recorded lower means for both high-SRS students (M = 77.06) and low-SRS students (M = 64.46). These results indicate a consistent advantage of POGIL across the two SRS groups, even though the interaction effect was not statistically significant.

e. Summary of ANOVA Results

Table 1 presents a summary of the two-way ANOVA results used to test the effects of instructional model, SRS level, and their interaction.

Table 1. Summary of Two-Way ANOVA

Source	Sum of Squares	df	Mean Square	F	Sig.	η^2
Instructional Model	1903.921	1	1903.921	20.385	.000	.290
SRS Level	684.432	1	684.432	7.328	.010	.104
Model × SRS Interaction	239.020	1	239.020	2.559	.118	.036
Error	3735.992	40	93.400			

f. Descriptive Statistics

Table 2 provides descriptive statistics for all groups based on instructional model and SRS level.

Table 2. Descriptive Statistics for Each Group

Instructional Model	SRS Level	Mean	SD	n
POGIL	High	85.59	7.40	10
	Low	82.35	8.70	12
Verification	High	77.06	9.88	10
	Low	64.46	11.80	12

These descriptive statistics reinforce the ANOVA findings, demonstrating consistently higher performance among students taught with POGIL and among those with higher scientific reasoning skills

3.2. Discussion

The results of this study demonstrate a clear main effect of instructional model, with students taught using Process Oriented Guided Inquiry Learning (POGIL) achieving significantly higher conceptual understanding of reaction-rate concepts than those taught through a verification approach. This finding indicates that the inquiry-based learning structure embedded in POGIL provides a more effective learning environment for developing conceptual understanding in chemistry. In POGIL classrooms, students engage in structured inquiry activities that require them to analyze data, construct explanations, and apply concepts to solve problems. Such learning processes promote active cognitive engagement and support meaningful knowledge construction. This interpretation aligns with the perspective of Lawson, (2004), who argues that active involvement in scientific reasoning processes plays a crucial role in facilitating conceptual change.

Compared with verification-based instruction, where concepts are typically explained before experiments are conducted to confirm known principles, POGIL emphasizes concept discovery through guided inquiry. Students are required to interpret experimental evidence and collaboratively develop conceptual explanations through structured learning cycles. The collaborative small-group setting further supports knowledge construction through peer discussion and instructor facilitation. Previous studies have reported similar benefits of POGIL in improving students' conceptual understanding and engagement in chemistry learning (Barthlow & Watson, 2014; Hanson, 2006; Mamombe et al., 2021; Moog & Spencer, 2008; Şen et al., 2015). The substantial effect size observed in this study ($\eta^2 = 0.29$) further indicates that the instructional model contributes meaningfully to students' learning outcomes, highlighting the practical educational significance of implementing inquiry-based approaches such as POGIL in chemistry classrooms.

In addition to the instructional model, the results also reveal a significant main effect of scientific reasoning skill (SRS). Students with higher levels of scientific reasoning achieved significantly better conceptual understanding of reaction-rate concepts compared with students with lower reasoning ability. This result suggests that scientific reasoning plays an important role in supporting students' ability to analyze relationships between variables, interpret experimental data, and construct scientific explanations. These findings are consistent with previous research indicating that

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reasoning ability is closely related to students' performance in science learning (Oloyede, 2012). The effect size associated with SRS ($\eta^2 = 0.10$) indicates a moderate influence, suggesting that reasoning skills represent an important cognitive factor that contributes to students' conceptual achievement in chemistry.

Despite the significant main effects observed for both instructional model and scientific reasoning skill, the interaction between these two variables was not statistically significant. This finding indicates that the relative effectiveness of POGIL compared with verification-based instruction does not depend significantly on students' levels of scientific reasoning. In other words, the advantage of POGIL appears to be relatively consistent across students with both high and low reasoning skills. From a statistical perspective, this suggests that the effects of instructional model and scientific reasoning operate independently rather than interactively in influencing students' conceptual understanding.

Nevertheless, the descriptive statistics provide interesting patterns that may offer insights into potential learning mechanisms. Students with high SRS generally achieved higher conceptual scores than students with low SRS in both instructional models, reflecting the role of advanced reasoning processes in interpreting chemical phenomena. Understanding reaction-rate concepts often requires correlational reasoning to relate variables such as concentration, surface area, and reaction rate, as well as proportional reasoning to interpret quantitative relationships between variables. Students with higher levels of scientific reasoning are typically more capable of performing these cognitive operations accurately, which may explain their superior performance in conceptual assessments. Similar patterns have been reported in previous studies showing that higher reasoning ability is associated with improved performance in reasoning-intensive chemistry tasks (Nnorom, 2013).

At the same time, the structured inquiry framework implemented in POGIL may provide additional cognitive support for students with lower levels of reasoning ability. Through guided questions, structured worksheets, and collaborative discussion, students are encouraged to interpret data, identify relationships between variables, and construct explanations based on evidence. Such scaffolding may help students gradually develop reasoning skills while simultaneously improving their conceptual understanding. Bao et al., (2009) argue that inquiry-based learning environments that explicitly engage students in reasoning processes can support the development of both conceptual understanding and scientific reasoning skills.

In contrast, verification-based instruction often presents conceptual relationships explicitly before experimentation takes place. While this approach can efficiently demonstrate scientific principles, it may limit opportunities for students to actively engage in the reasoning processes required to construct knowledge independently. As a result, students may rely more heavily on memorization rather than developing deeper conceptual understanding and reasoning ability.

From an educational perspective, the magnitude of the instructional model effect observed in this study suggests that adopting inquiry-oriented instructional strategies such as POGIL can substantially improve students' conceptual learning outcomes in chemistry. At the same time, the significant role of scientific reasoning skill highlights the importance of integrating reasoning-oriented activities into chemistry instruction. Instructional approaches that simultaneously develop conceptual understanding and reasoning ability may therefore be particularly beneficial for improving overall student achievement in science learning.

Overall, the findings of this study contribute to the growing body of research supporting the effectiveness of inquiry-based learning approaches in chemistry education. The results demonstrate that POGIL consistently enhances students' understanding of reaction-rate concepts while also confirming the important role of scientific reasoning skill in determining students' academic performance. Although no interaction effect was detected, the independent contributions of instructional model and reasoning ability suggest that both pedagogical design and students' cognitive characteristics should be considered in efforts to improve chemistry learning. Future studies involving larger samples and diverse learning contexts are recommended to further investigate the potential interaction between instructional approaches and students' reasoning abilities in inquiry-based science instruction.

4. CONCLUSION

The study confirms that the Process Oriented Guided Inquiry Learning (POGIL) approach significantly improves students' conceptual understanding of reaction-rate concepts, with a large effect size (η^2 = 0.29), independent of students' scientific reasoning skill (SRS). SRS itself also contributes positively to conceptual outcomes (η^2 = 0.10). While no interaction between instructional model and SRS was detected, POGIL consistently outperforms verification instruction. Limitations include small sample size, quasi-experimental design, dichotomized SRS, and brief instruction. Future research should use larger, diverse samples, continuous moderation analysis, longitudinal designs, and two-tier diagnostics to explore misconception change and long-term learning. These findings underscore POGIL's effectiveness and the pivotal role of scientific reasoning in chemistry learning.

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