



STEM Hybrid Research-Based Learning versus Discovery Learning: Which Better Promotes Scientific Reasoning in Environmental Change Education?

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Abstract: This study aims to examine the effect of the STEM Hybrid Research-Based Learning (STEM-Hybrid RBL) model on high school students' scientific reasoning skills in the context of environmental change, compared with the Discovery Learning model. The study employed a quasi-experimental method using a pretest-posttest control group design and involved 84 tenth-grade students from SMA Negeri 1 Kota Sukabumi, Indonesia, who were selected through purposive sampling and assigned to an experimental class ($n = 42$) and a control class ($n = 42$). The research instrument was a multiple-choice scientific reasoning test that met the validity criteria and demonstrated a high reliability coefficient (0.94). Data were analyzed using the Mann-Whitney U test because the data did not meet the assumptions of normality and homogeneity. Effect size (r) and N-gain analyses were also conducted to examine the magnitude of the difference and the improvement in each scientific reasoning indicator. The results revealed a statistically significant difference between the experimental and control classes ($U = 459.50$, $Z = -3.860$, $p < .001$), with a medium-to-large effect size ($r = .42$). The experimental class achieved a higher mean posttest score (91.65) than the control class (77.75). The N-gain analysis for each indicator showed the greatest improvement in proportional reasoning and correlational reasoning, whereas identifying and controlling variables showed the lowest improvement in the experimental class. Student responses to the STEM-Hybrid RBL model were categorized as good to very good, with an average score of 79.6%. These findings indicate that STEM-Hybrid RBL is a promising learning model for improving high school students' scientific reasoning skills and may be applicable to various science learning contexts at the secondary school level.

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Introduction

Scientific reasoning skills are a fundamental competency in 21st-century science education, encompassing the ability to formulate hypotheses, identify and control variables, collect and analyze data, draw evidence-based conclusions, and systematically reflect on the thinking process (Lawson, 2004; Zhou et al., 2016). These skills are not only relevant in an academic context but are also essential for students' readiness to face increasingly complex, dynamic, and data-driven global challenges (Shofiyah et al., 2013; Utami et al., 2019). Within the framework of the Merdeka Curriculum, the development of scientific reasoning is an integral part of the Pancasila learner profile, which emphasizes the strengthening of critical thinking and the ability to solve real-world problems scientifically (Kemdikbud, 2022). Good scientific reasoning has been shown to positively contribute to student performance in science



learning, foster deeper conceptual understanding, and prepare students to adaptively address various real-life challenges (Mandella et al., 2021; Piraksa et al., 2014).

Nevertheless, the state of scientific reasoning among Indonesian students generally remains concerning. The results of the 2022 Programme for International Student Assessment (PISA) study placed Indonesia at an average score of 383 points, far below the OECD average of 485 points (OECD, 2023). This gap indicates that science education in Indonesia has not optimally developed aspects of scientific reasoning, such as controlling variables, probabilistic reasoning, correlational reasoning, and hypothesis-deductive reasoning (Mandella et al., 2021). A similar situation was found in a preliminary study conducted at a public high school in Sukabumi City, where students' scientific reasoning test scores reached only 43.23%. These findings suggest a significant gap between the demands for scientific reasoning competencies and the actual conditions in the field, largely caused by the continued dominance of conventional teaching methods that prioritize memorization over active engagement in the scientific process (Fikriana et al., 2023; Sumarni & Kadarwati, 2020).

Various efforts have been made to improve students' scientific reasoning through innovative learning models. The integration of the STEM approach into science education has also been shown to foster higher-order thinking and scientific skills through the resolution of real-world, interdisciplinary problems (Bybee, 2013; Kelley & Knowles, 2016). On the other hand, Research-Based Learning (RBL), rooted in constructivist philosophy, positions students as active researchers who construct knowledge through empirical experiences (Brew & Saunders, 2020; Piraksa et al., 2014). The use of hybrid learning environments that combine face-to-face and online learning has also been shown to increase flexibility and student engagement, particularly in contexts where laboratory facilities are limited (Swandi et al., 2025). However, most of these studies have only explored a single approach in isolation and have not yet systematically integrated them into a single, comprehensive model; consequently, there is a gap in the literature regarding learning models capable of comprehensively developing all indicators of scientific reasoning. Furthermore, existing studies also tend to measure scientific reasoning in a fragmented manner, focusing only on one or a few specific indicators such as control of variables or hypothetico-deductive reasoning (Lawson, 2004; Piraksa et al., 2014), without providing a comprehensive picture of the simultaneous improvement across all six indicators of scientific reasoning. This gap underscores the need for research that not only integrates these approaches into a cohesive learning model but also tests it experimentally using comprehensive measures of scientific reasoning at the secondary school level.

Recent developments indicate efforts to integrate these approaches more cohesively. Swandi et al., (2025) developed the STEM Hybrid Research-Based Learning (STEM-Hybrid RBL) model, which combines the STEM approach, structured research activities, and a hybrid learning system within a single learning framework specifically designed to enhance scientific reasoning. This development study, published in the EURASIA Journal of Mathematics, Science and Technology Education, demonstrates that the model is valid, practical, and statistically effective with a t -value (48) = -4.670; $p < 0.001$ and a Cohen's d effect size of -1.321 (large category) in improving college students' scientific reasoning. Nevertheless, the study by Swandi et al., (2025) is limited to the context of higher education within a single program of study with a relatively short implementation period; therefore, the researchers explicitly suggest expanding the application of this model to other educational levels, including secondary schools, to test its flexibility and relevance in different contexts. At the high school level, the application of the STEM-Hybrid RBL model to topics that



require hands-on investigation, such as environmental change, has not been studied previously. Environmental change topics possess characteristics highly relevant to the development of scientific reasoning, as they involve real-world phenomena that students can observe, measure, and analyze directly (Khusna & Kuswanti, 2024). In particular, investigating environmental change phenomena, such as measuring indicators of environmental quality and relating them to human activities, stimulates proportional reasoning (comparing quantities and rates), correlational reasoning (relating environmental factors to their impacts), identification and control of variables (isolating the factors that drive change), and hypothetico-deductive reasoning (proposing and testing explanations for observe changes, while conservation and probabilistic reasoning are engaged when students interpret material cycles and the uncertainty of environmental data. Therefore, there is a significant research gap regarding the effectiveness of the STEM-Hybrid RBL model in enhancing high school students' scientific reasoning, particularly in the context of environmental change topics.

Based on the above discussion, this study aims to analyze students' scientific reasoning following the implementation of the STEM Hybrid Research-Based Learning model on the topic of environmental change, to examine the differences in scientific reasoning between students who learn using this model and those who learn using the Discovery Learning model, and to describe students' responses to the learning process. The hypothesis tested is that the STEM Hybrid RBL model has a significant effect on high school students' scientific reasoning on the topic of environmental change compared to the Discovery Learning model. This study contributes empirical evidence on the transferability of the STEM-Hybrid RBL model from higher education to the secondary school level, provides a comprehensive picture of its effect across all six scientific reasoning indicators rather than isolated indicators, and offers practical insight for science teachers into which indicators respond strongly to the model and which need additional support.

Research Method

This study employed a quasi-experimental design aimed at determining the effect of the treatment on the variables under investigation (Sugiyono, 2010). The experimental class was given the STEM Hybrid Research-Based Learning model, while the control class used the Discovery Learning model. The study population comprised all 10th-grade students at SMA Negeri 1 Kota Sukabumi, consisting of 12 classes, and the study was conducted over two class sessions. Because the school's intact classes were used, the sample was determined by purposive sampling (Sugiyono, 2010), in which classes were deliberately matched on the equivalence of the biology teachers, a relatively similar number of students, the suitability of the material and the allocation of instructional time, and student learning outcomes. Based on this process, Class X-10 was selected as the experimental class and Class X-4 as the control class.

Students' scientific reasoning was measured with a multiple-choice test administered before instruction (pretest) and after instruction (posttest) that met validity and reliability criteria. Normality was tested with the Shapiro-Wilk test and homogeneity of variance with Levene's test. Because both assumptions were not met, the groups were compared using the nonparametric Mann-Whitney U test, and the magnitude of the difference was expressed as the effect size r ($r = |Z|/\sqrt{N}$). Improvement on each scientific reasoning indicator was analyzed using N-Gain. All analyses were performed using the Anates program and IBM SPSS Statistics 25 for Windows.



Results and Discussion

The instrument was tested for validity and reliability before the intervention. All items were valid, and the reliability coefficient was 0.94, which falls into the very high category (Arikunto, 2013), making the instrument suitable for measuring students' scientific reasoning. Table 1 presents the descriptive statistics of the posttest scores.

Table 1. Descriptive Statistics of Students' Scientific Reasoning

Description	Class	
	Experiment	Control
Number (N)	42	42
Max	100	100
Min	83,3	55,5
Mean	91,65	77,75

Table 1 shows that the posttest means of the experimental class using the STEM-Hybrid RBL model (91.65) was higher than that of the control class using Discovery Learning (77.75), a difference of 13.90 points. The experimental class also had a much higher minimum score (83.3 versus 55.5), indicating a more even score distribution and a smaller achievement gap among students (Swandi et al., 2025). Before hypothesis testing, normality was tested using the Shapiro-Wilk test, which is suitable for the sample size of 42 students per class (Razali & Wah, 2011), and homogeneity of variance was tested using Levene's test. The results are presented in Table 2.

Table 2. Results of Normality and Homogeneity Tests

Assumption test	Class	Sig. (p)	Decision
Normality (Shapiro-Wilk)	Experiment	<0.001	Not normal
	Control	0.012	Not normal
Homogeneity (Levene)	Both classes	0.002	Not homogeneous

Table 2 shows that the data in both classes were not normally distributed ($p < 0.001$ and $p = 0.012$, both below 0.05) and that the variances were not homogeneous ($p = 0.002$). Since both parametric assumptions were violated, the Mann-Whitney U test was used as the appropriate alternative for comparing two independent groups (Creswell & Creswell, 2018). The results, including the effect size, are presented in Table 3.

Table 3. Results of the Mann-Whitney U Test and Effect Size

Class	N	Mean Rank	U	Z	Asymp. Sig. (2-tailed)	r
Experiment	42	52.56	459.50	-3.860	<0.001	0.42
Control	42	32.44				

The Mann-Whitney U test showed a significant difference in scientific reasoning between the two classes ($U = 459.50$, $Z = -3.860$, $p < 0.001$), with a higher mean rank in the experimental class (52.56) than in the control class (32.44); therefore, H_0 is rejected and H_1 is accepted. The effect size was $r = 0.42$ ($r = |Z|/\sqrt{N} = 3.860/\sqrt{84}$), a medium-to-large effect (Cohen, 1988), indicating that the superiority of the STEM Hybrid RBL model over Discovery Learning is practically meaningful and not merely statistically significant. N-Gain analysis was then conducted to determine the improvement on each scientific reasoning indicator, categorized as high ($g \geq 0.70$) or medium ($0.30 \leq g < 0.70$) following Hake, (1998). The mean N-Gain values are presented in Table 4 and illustrated in Figure 1.

Table 4. Mean N-Gain per Scientific Reasoning Indicator

Scientific Reasoning Indicator	Experiment	Control
Conservation reasoning	0.76 (High)	0.41 (Medium)
Proportional reasoning	0.97 (High)	0.53 (Medium)



Probabilistic reasoning	0.45 (Medium)	0.33 (Medium)
Correlational reasoning	0.93 (High)	0.57 (Medium)
Identification and control of variables	0.40 (Medium)	0.61 (Medium)
Hypothetico-deductive reasoning	0.61 (Medium)	0.38 (Medium)

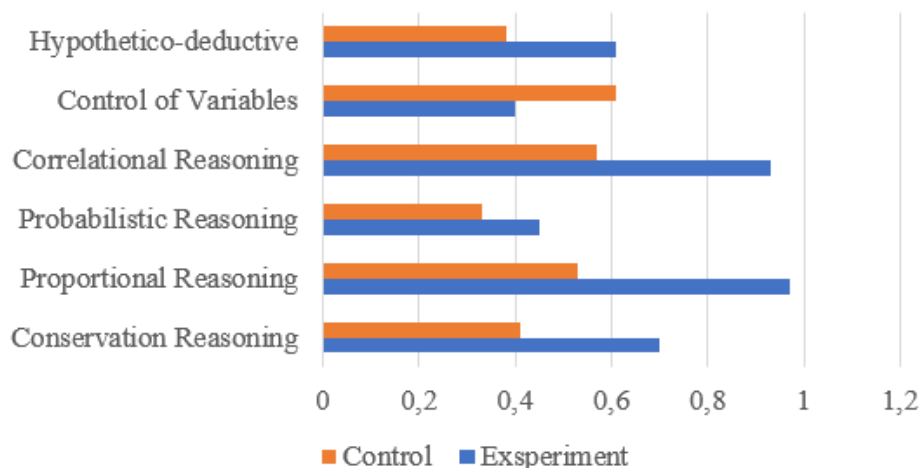


Figure 1. N-Gain Diagram of Scores by Scientific Reasoning Indicator for the Experimental and Control Classes

Table 4 and Figure 1 show that the experimental class obtained higher N-Gain values than the control class on five of the six indicators. Proportional reasoning recorded the highest improvement in the experimental class (0.97), followed by correlational reasoning (0.93), conservation reasoning (0.76), hypothetico-deductive reasoning (0.61), probabilistic reasoning (0.45), and identification and control of variables (0.40). The control class using Discovery Learning showed lower and uneven improvement, particularly in probabilistic (0.33) and hypothetico-deductive reasoning (0.38). The exception was identification and control of variables, where the control class (0.61) exceeded the experimental class (0.40).

The results of this study indicate that the STEM Hybrid Research-Based Learning model is significantly more effective in improving high school students' scientific reasoning skills regarding environmental change than the Discovery Learning model. These findings can be scientifically explained through three main mechanisms that constitute the structural strengths of the STEM Hybrid RBL model.

First, the STEM-Hybrid RBL model provides students with the opportunity to take an active role as researchers throughout the learning process. Through this model, students engage in various scientific activities, ranging from identifying problems, designing research, conducting hybrid research, analyzing data, to presenting results and reflecting on the process (Swandi et al., 2025). Student involvement in all these stages helps develop scientific reasoning skills more comprehensively because each indicator of scientific reasoning is practiced within a series of interrelated learning activities. Unlike Discovery Learning, which places greater emphasis on the process of discovering concepts through teacher guidance, STEM Hybrid Research-Based Learning provides a more tangible and structured research experience, thereby giving students more opportunities to apply scientific thinking skills in problem-solving (Bruner, 1961; Syah, 2004).

Second, the superiority of the STEM-Hybrid RBL model is particularly evident in the higher improvement in proportional reasoning observed in the experimental class, which also demonstrates the contribution of integrating mathematical elements into the STEM-Hybrid RBL model. During the Hybrid Research activities, students took measurements, recorded



their observations, and compared the quantitative data they obtained. These activities indirectly train students' ability to understand relationships between quantities and interpret data proportionally in real-world situations (Bybee, 2013). Learning that utilizes real-world contexts like this helps students understand concepts of comparison and quantitative relationships better than learning that relies solely on examples or hypothetical situations (Saldarriaga-Zambrano & Reyes-Ávila, 2024). Additionally, the correlational reasoning indicator also showed a significant increase. This can be explained by the fact that the Hybrid Research and Analysis and Discussion components of this model explicitly encourage students to collect numerical data from real experiments and then analyze patterns of relationships between variables based on that data (Swandi et al., 2025). The mathematics component of the STEM approach strengthens these skills through the creation of comparison tables and graphs that require students to identify quantitative correlations. These results are consistent with the findings of Mandella et al., (2021), who stated that correlational skills are the indicator of scientific reasoning most responsive to empirically based learning interventions. In contrast, the control class using the Discovery Learning model showed a smaller improvement because the processed data were derived from videos and literature, rather than from direct measurements, thus limiting cognitive engagement in the process of correlational reasoning (Bruner, 1961).

Third, identification and control of variables was the weakest indicator in the experimental class and the only indicator on which the experimental class did not outperform the control class. This can be explained by Piaget's theory of cognitive development (as cited in Khan & Krell, 2019), which states that controlling variables is a form of advanced formal operational reasoning that requires time and repeated experience to develop. High school students encountering structured experiments for the first time tend not to operationalize the concept of controlled variables consistently, even after explicit guidance (Krell et al., 2022). The open-ended investigations in STEM-Hybrid RBL may have placed a heavier cognitive load on students, who had to determine variables independently while also collecting and analyzing real data. This finding is consistent with Swandi et al., (2025), who found that control of variables showed the lowest improvement among university students, indicating that long-term coaching beyond a single learning cycle is required.

The significant improvement in hypothetico-deductive reasoning skills in the experimental class indicates that the STEM-Hybrid RBL model is effective in providing a better learning experience for students in formulating and testing hypotheses. During the Exploration and Design phase, students are guided to formulate hypotheses based on the problems they encounter, while in the Communication and Reflection phase, students evaluate the validity of those hypotheses using data obtained from their research findings (Swandi et al., 2025). This activity provides students with the opportunity to directly understand the relationship between initial conjectures and empirical evidence. Learning experiences that involve testing hypotheses through real data are considered more effective in developing hypothetico-deductive reasoning compared to learning that relies solely on theoretical studies or literature discussions (Lawson, 2004). This finding aligns with the research by Fikriana et al., (2023), which shows that student engagement in the process of formulating hypotheses, conducting experiments, and drawing conclusions based on research results can enhance higher-order scientific reasoning skills.

In general, the results of this study provide evidence that the STEM-Hybrid RBL model is effective in improving high school students' scientific reasoning skills regarding environmental change. These findings support the results of Swandi et al., (2025), who



previously developed and tested this model at the university level. Thus, this study demonstrates that the STEM-Hybrid RBL model is not only effective for university students but can also be applied to high school students. These results also support the recommendation by Swandi et al., (2025) to test the application of the STEM-Hybrid RBL model at different educational levels.

Although the research subjects, learning materials, and instruments differed, the pattern of results was similar to that of Swandi et al., (2025). The STEM-Hybrid RBL model improved all indicators of students' scientific reasoning, suggesting its potential for various science learning contexts at the secondary school level.

Research findings demonstrating the superiority of the STEM-Hybrid RBL model in enhancing students' scientific reasoning skills are also supported by data from student response questionnaires, worksheet assessments, and observations of classroom implementation. Questionnaire results from the experimental class showed an average percentage of 79.6%, with ratings ranging from good to very good across all assessed aspects. These findings indicate that students responded positively to the implemented instructional approach. This positive response aligns with the improvement in students' scientific reasoning skills. Chang et al., (2018) state that student engagement and interest during the learning process can support the development of better scientific reasoning skills.

Similar results were also evident in the LKPD assessment scores. Most groups in the experimental class achieved the "very good" category, with percentages ranging from 83% to 96%. In contrast, groups in the control class generally received a "good" rating, with percentages ranging from 63% to 75%. These results indicate that students in the experimental class were able to complete learning tasks and activities more effectively. This ability reflects students' skills in processing data, analyzing information, and presenting results in writing, which are linked to the improvement in scientific reasoning skills achieved.

Additionally, the results of observations on the implementation of learning indicate that the difference in scientific reasoning abilities between the experimental and control classes is influenced by differences in the learning processes that took place. The implementation of the STEM-Hybrid RBL model in the experimental class reached an average of 92% in the "very good" category, while the implementation of the Discovery Learning model in the control class reached 85% and also fell into the "very good" category. Although both models were implemented effectively, activities related to data collection and analysis in the experimental class were more successful. This is evident from the hybrid research phase, which achieved a 75% completion rate, whereas the data collection phase in the control class reached only 67%. This finding may help explain why identification and control of variables remained the lowest indicator in the experimental class.

Overall, the results of the scientific reasoning tests, student response questionnaires, worksheet assessments, and observations of classroom instruction were consistent with one another. These findings reinforce the conclusion that the STEM-Hybrid RBL model is more effective in helping students develop scientific reasoning skills, both in terms of the learning process and learning outcomes.

Conclusion

The STEM Hybrid Research-Based Learning model is effective in improving high school students' scientific reasoning skills on the topic of environmental change and produces better outcomes, with a meaningful practical effect, than Discovery Learning. The model improved all six scientific reasoning indicators, most strongly proportional and correlational



reasoning, whereas identification and control of variables remained the weakest and requires further reinforcement. Students' positive responses and the high quality of their worksheet completion support the model as a viable alternative for science learning at the secondary school level.

These findings have implications for curriculum design and theory development. For high school science curricula, units such as environmental change can be organized as multi-stage research cycles, from problem identification and data collection to analysis and reflection, with face-to-face and online components that compensate for limited laboratory facilities, in line with the Merdeka Curriculum's emphasis on critical thinking and real-world problem solving. Theoretically, the results indicate that STEM integration and research-based learning are complementary: quantitative, data-driven investigation appears to strengthen proportional and correlational reasoning, while weaker gains in controlling variables suggest that research-based models require explicit scaffolding of experimental design to develop all dimensions of scientific reasoning.

Recommendation

Since identification and control of variables was the weakest indicator, teachers applying STEM-Hybrid RBL are advised to scaffold this skill explicitly and gradually. Practical steps include pre-investigation exercises in which students classify manipulated, responding, and controlled variables in short experimental scenarios; worksheets (LKPD) that require students to state the variables and justify the controls before collecting data; contrasting examples of fair and unfair tests; and fading support across successive research cycles, from guided to open investigations (Khan & Krell, 2019; Krell et al., 2022). Future research is recommended to implement the model over a longer period or across multiple learning cycles, to test interventions that specifically target control of variables (for example, different levels of scaffolding), and to examine why the control class performed better on this indicator. Future studies could also consider students' and teachers' readiness and the availability of supporting facilities as variables influencing implementation, and test the model in other science subjects, such as Physics and Chemistry, and at other educational levels, such as junior high school.

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