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The Effectiveness of Black's Principles with Modeling-based Learning (MbL) to Improve Students' Science Process Skills

Firza Farahdiba Daeng[1*], Dea Ramadhana Zsa Zsa Alifah[1], Budi Jatmiko[1], Zainul Arifin Imam Supardi[1], Hanan Zaki Alhusni[1], Nina Fajriyah Citra[2]

[1]Universitas Negeri Surabaya, Surabaya, Indonesia
[2]Monash University,Wellington, Australia

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ABSTRACT

Objective: *This study aims to examine the effectiveness of the Modeling-based Learning (MbL) model in improving students' science process skills (SPS) on the topic of Black's Principle. SPS is essential for mastering STEM, yet remains relatively low among Indonesian students, as indicated by PISA and TIMSS results.* ***Method:*** *The research employed a quasi-experimental design using a pretest-posttest control group design. Two high school classes, each consisting of 30 students, participated in the study. The instruments used included an SPS test and questionnaires that measured skills such as observing, formulating hypotheses, conducting experiments, and interpreting and communicating data. Data analysis involved N-Gain calculations, normality tests, and paired t-tests to confirm statistical significance.* ***Results:*** *The findings revealed that the experimental class taught using the MbL model showed a significant improvement in SPS, with an average N-Gain score of 0.8 (high category). In contrast, the control class, which did not receive MbL-based instruction, only reached an average N-Gain score of 0.5 (medium category). Statistical tests confirmed the significance of these differences, demonstrating the positive impact of the MbL model on SPS development.* ***Novelty:*** *This study highlights the potential of the MbL approach as an innovative and effective teaching model to enhance science process skills at the secondary school level. By integrating modeling activities into learning, the MbL strategy provides students with deeper engagement and better mastery of scientific inquiry processes compared to traditional methods.*

INTRODUCTION

Science education in the 21st century is expected to go beyond conceptual knowledge, cultivating critical, analytical, and evidence-based scientific thinking. The integration of science process skills (SPS) into learning is considered essential to prepare students for global challenges that demand problem-solving, creativity, and innovation (NRC, 2012; Bybee, 2013). Ideally, students should not only master scientific concepts but also be able to design experiments, analyze data, and apply science in real-world contexts, aligning with STEM education goals.

However, international assessments highlight that Indonesian students still perform below the global average in science literacy. Results from the Programme for International Student Assessment (PISA) 2018 placed Indonesia at rank 71 out of 79 participating countries in science (OECD, 2019). Similarly, the Trends in International Mathematics and Science Study (TIMSS) 2019 indicated that many Indonesian students struggle with applying concepts in experimental and problem-solving contexts (Mullis et al., 2020). These findings demonstrate that science education in Indonesia has not yet fully achieved its intended outcomes in developing SPS.

One contributing factor to this low achievement is the dominance of teacher-centered instructional practices. Many science classes emphasize rote memorization and procedural laboratories, leaving little room for inquiry, exploration, or independent reasoning (Suprapto, 2020). Wahyudi et al. (2021) found that 78% of science experiments in secondary schools followed predetermined steps without allowing students to formulate hypotheses or analyze results critically. As a result, students are not adequately trained to think and act like scientists, and their SPS remain underdeveloped.

Several pedagogical innovations have been proposed to address these challenges. Inquiry-based learning and problem-based learning have shown promise in fostering students' engagement and scientific reasoning (Hmelo-Silver et al., 2007; Furtak et al., 2012). More recently, Modeling-based Learning (MbL) has gained attention as an approach where students actively construct, test, and revise models to explain scientific phenomena. A meta-analysis by Louca and Zacharia (2012) reported that MbL significantly enhances students' conceptual understanding and reasoning abilities across diverse science topics.

The effectiveness of MbL has been confirmed in various contexts. For example, in South Korea, the integration of MbL in the 2024 science curriculum increased students' SPS by 15% (Kim & Park, 2025). Similarly, international studies have shown that MbL promotes deeper conceptual comprehension, critical thinking, and collaborative learning, which align with 21st-century learning competencies (Windschitl et al., 2008; Schwarz et al., 2009). These findings suggest that MbL has the potential to address the weaknesses of traditional science education in Indonesia.

Nevertheless, the implementation of MbL is not without challenges. Teachers often face difficulties in designing model-based tasks due to limited training and resources (Clement, 2000). Moreover, MbL requires sufficient classroom time and flexible curriculum structures, which are often constrained in Indonesian schools (Rahmawati et al., 2019). Without proper support, MbL could risk being reduced to procedural modeling rather than meaningful scientific reasoning. Thus, it is necessary to examine how MbL can be effectively adapted in the Indonesian context.

Considering these opportunities and challenges, there is an urgent need for empirical studies that test the effectiveness of MbL in improving Indonesian students' SPS. Prior studies in Western and East Asian contexts have demonstrated its potential, but limited evidence exists from developing countries with resource constraints (Louca et al., 2023). This study addresses that gap by applying MbL to the topic of Black's Principle, which requires students to engage in experimental design, hypothesis formulation, and data interpretation—core aspects of SPS.

Therefore, this research aims to investigate the effectiveness of the MbL model in enhancing students' SPS in Indonesian secondary schools, specifically on the topic of Black's Principle. The novelty of this study lies in contextualizing MbL within a developing country setting, where infrastructure, teacher readiness, and socioeconomic backgrounds present unique challenges. By providing empirical evidence on the applicability of MbL in Indonesia, this study offers valuable insights for curriculum developers and educators seeking to reform science teaching toward more inquiry- and model-based approaches.

RESEARCH METHOD

The type of research used in this study is a quasi-experimental design, which is widely used in education because it allows researchers to test the effect of instructional interventions in real classroom contexts. Quasi-experiments are particularly appropriate in school-based research where random assignment is often not feasible, but comparison across groups is still possible (Lohr, 2019; Daniel, 2020). This approach helps determine the causal relationship between the independent variable Modeling-based Learning (MbL) on Black's Principle and the dependent variable students' science process skills (SPS) while recognizing that some extraneous variables cannot be completely controlled.

This study involved two intact groups: an experimental class and a control class. The experimental class received instruction using the MbL approach, while the control class was taught using conventional teacher-centered methods such as lectures and guided practice. To ensure validity, both groups studied the same topic and materials. The pretest-posttest control group design was implemented, enabling measurement of learning gains by comparing students' performance before and after the intervention. This design is considered one of the most reliable quasi-experimental methods for educational research (Schlotter et al., 2021).

The procedure consisted of three stages. First, a pretest was administered to both groups to identify baseline SPS levels. Next, the intervention was carried out, with the experimental group engaging in MbL-based activities constructing, testing, and refining models while the control group followed conventional instruction. Finally, a posttest was administered to both groups to evaluate improvement. This method allows researchers to assess the effectiveness of MbL in fostering critical skills such as observing, hypothesizing, experimenting, analyzing, and communicating scientific findings (Zhang & Linn, 2022).

Data analysis involved calculating the normalized gain (N-Gain) to measure relative improvement between pretest and posttest scores, which is a widely recognized method in science education research (Bao, 2020). In addition, statistical tests were applied, including normality testing and paired sample t-tests, to determine whether the observed differences between groups were statistically significant. The combination of N-Gain and inferential statistics provides robust evidence of learning effectiveness and helps strengthen the internal validity of the study (Köseoglu & Mercan, 2019).

Sample

This study was conducted on black principles. The population used was class F11.1 as the experimental class and F11.2 as the control class, with 30 students in each class. The flow of this study can be seen in Table 1.

Table 1. Research design

No	Class	Pre-test	Treatment	Post-test
1	Experiment	O_1	X	O_3
2	Control	O_2	-	O_4

Explanation:
O_1 : Pre-test score for the experimental class
O_2 : Pre-test score for the control class
X : Learning of Black's principles with MbL
O_3 : Post-test score for the experimental class
O_4 : Post-test score for the control class

Instrument

The instruments used in this study were science process skill assessments given in test questions and questionnaires filled out by students at the end of the lesson. The indicators for the science process skill test questions are shown in Table 2.

Table 2. SPS indicator

SPS Aspect	Example
Observing or Orientation	Observing a video about phenomena in everyday life
Formulating Hypotheses	Formulating a hypothesis based on the observed video
Conducting Experiments	Conducting practical work directly or using other media
Classifying Data in a Table	Entering the data obtained from the experiment into a table
Visualizing Data in Graphs	Creating a graph from the data obtained during the experiment
Interpreting Data	Interpreting the data generated from the experiment
Drawing Conclusions	Making conclusions based on experimental data
Communicating	Presenting group discussion results using effective sentences

Data Analysis

Pre-test and post-test data of students were collected, then n-gain analysis was conducted. This analysis was used to determine students' physics learning before and after they were given treatment.

$$\langle g\rangle = \frac{S_{\text{posttest}} - S_{\text{pretest}}}{S_{\text{maximal}} - S_{\text{pretest}}}$$

Explanation:
$<g>$ = Gain value
$S_{posttest}$ = Posttest value
$S_{pretest}$ = Pre-test value
$S_{maximal}$ = Maximum value

The criteria for interpreting N-gain are in accordance with Table 3.

Table 3. n-Gain Criteria

Value	n-Gain Criteria
n-gain < 0.3	Low
0.3 ≤ n-gain ≤ 0.7	Medium
0.7 < n-gain	High

After conducting statistical analysis on the science process skills of the students, they were given treatment using Modeling-based Learning (MbL).

RESULTS AND DISCUSSION

Results

To determine whether the data from both the experimental and control groups were normally distributed, a normality test was conducted using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The results of the normality test are presented in Table 4.

Table 4. Tests of normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Class	Statistic	df	Sig.	Statistic	df	Sig.
Science Process Skills	pre-test experiment	.171	30	.025	.937	30	.075
	post-test experiment	.145	30	.106	.921	30	.028
	pre-test control	.166	30	.034	.936	30	.072
	post-test control	.148	30	.092	.967	30	.464

a. Lilliefors Significance Correction

Based on Table 4, it can be seen that the significance values for most of the data in the Kolmogorov-Smirnov test were below 0.05, while in the Shapiro-Wilk test some were above and some below 0.05. Following the assumption that the Shapiro-Wilk test is more reliable for small samples ($n < 50$), the results indicate that several data sets, particularly the experimental post-test, did not meet the normality assumption ($p < 0.05$). Despite this, other data sets showed p-values greater than 0.05, suggesting normal distribution. Therefore, in the subsequent analysis, both parametric and non-parametric statistical approaches were considered to ensure the validity of the findings.

To determine the effect of the treatment on students' science process skills (SPS), a paired sample t-test was conducted by comparing the pre-test and post-test scores of both the experimental and control groups. The descriptive results of the paired sample statistics are shown in Table 5.

Table 5. Results of paired t-tests for pre-test and post-test

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pre-test experiment	34.00	30	9.040	1.650
	post-test experiment	87.20	30	7.725	1.410
Pair 2	pre-test control	32.83	30	11.271	2.058
	pre-test control	66.83	30	10.866	1.984

Table 5 shows that the mean score of the experimental group increased significantly from 34.00 in the pre-test to 87.20 in the post-test, with a standard deviation of 9.040 and 7.725, respectively. This suggests that students in the experimental group experienced substantial improvement after the application of the Modeling-based Learning (MbL) approach. Meanwhile, the control group's mean score rose from 32.83 to 66.83, also showing an improvement, although the increase was not as high as in the experimental group. These results indicate that while both instructional methods improved students' SPS, the MbL approach produced greater learning gains compared to the conventional method.

To provide a clearer comparison of students' performance before and after the learning intervention, the average scores of the experimental and control groups on the pre-test and post-test are presented in Table 6.

Table 6. Average scores of the pre-test and post-test

Class	Test Type	
	Pre-Test	Post-Test
Experiment	34	87.2
Control	32.8	66.8

Table 6 shows that both groups experienced an increase in average scores from pre-test to post-test. The experimental class improved from a mean score of 34.0 to 87.2, while the control class increased from 32.8 to 66.8. Although both groups showed progress, the experimental group achieved a significantly higher improvement, indicating that the Modeling-based Learning (MbL) approach was more effective in enhancing students' science process skills compared to conventional teaching methods.

To illustrate the improvement in students' science process skills more clearly, the results of the pre-test and post-test for both the experimental and control classes are presented in Figure 1.

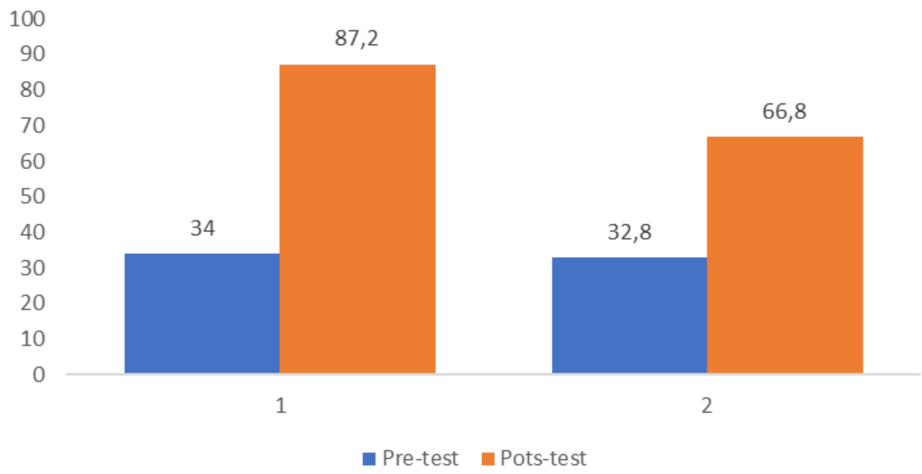

Figure 1. Graph of average pre-test and post-test scores for science process skills

Figure 1 shows a significant increase in the average score of the experimental class, from 34.0 in the pre-test to 87.2 in the post-test. Meanwhile, the control class also showed improvement, rising from 32.8 to 66.8. However, the difference between pre-test and post-test scores in the experimental class was much greater than in the control class. This finding indicates that the Modeling-based Learning (MbL) approach had a stronger impact on enhancing students' science process skills compared to the conventional teaching method.

To measure the relative improvement of students' learning outcomes, the normalized gain (N-Gain) was calculated for both the experimental and control classes. The results are shown in Table 7.

Table 7. n-Gain result

Class	n-Gain	Criteria
Experiment	0.8	High
Control	0.5	Low

Table 7 demonstrates that the experimental class achieved an N-Gain value of 0.8, which falls into the high category, while the control class obtained an N-Gain value of 0.5, categorized as medium. These results indicate that although both groups experienced an increase in science process skills, the improvement in the experimental group was significantly greater. This finding confirms that the use of the Modeling-based Learning (MbL) approach was more effective in enhancing students' science process skills compared to conventional teaching methods.

Discussion

The findings of this study revealed that the pre-test scores of students in both the experimental and control classes were relatively similar, indicating comparable baseline levels of science process skills (SPS). However, after the intervention, the post-test results demonstrated a substantial difference between the two groups. The experimental class, which was taught using the Modeling-based Learning (MbL) approach, achieved an average post-test score of 87.2, compared to 66.8 in the control class. This suggests that MbL has a greater impact on improving SPS than conventional instruction.

The calculation of normalized gain (N-Gain) further supports this conclusion. The experimental group obtained an N-Gain value of 0.8, which falls into the high category, while the control group achieved only 0.5, categorized as medium. According to Hake (1999), an N-Gain above 0.7 reflects a high level of learning effectiveness. Thus, the implementation of MbL not only improved students' SPS but did so to a significant degree compared to traditional teaching. This finding is consistent with studies reporting that MbL is an effective strategy for fostering scientific reasoning and conceptual understanding (Zhang & Linn, 2022; Louca et al., 2023).

One of the reasons behind the effectiveness of MbL lies in its emphasis on active construction, evaluation, and revision of scientific models. Unlike traditional procedural learning, where students follow predetermined laboratory steps, MbL requires learners to design experiments, interpret data, and test hypotheses through cycles of inquiry. This aligns with the argument of Hadi et al. (2024), who found that the majority of science laboratory activities in Indonesian schools remain verification-based, providing little opportunity for students to engage in critical or exploratory thinking. In contrast, MbL situates students in authentic problem-solving contexts where they practice essential SPS such as observing, hypothesizing, experimenting, and communicating findings.

Moreover, MbL facilitates collaborative and contextualized learning. When students construct and refine models in groups, they are required to engage in scientific discourse, negotiate meaning, and communicate effectively. Such practices are essential for developing not only academic skills but also transferable competencies that align with 21st-century education goals (Kuhn, 2010; Osborne, 2014). Kurnaz and Arslan (2022) argue that strong SPS contribute not only to academic success but also to the cultivation of scientific habits of mind that students can apply in everyday life. The results of this study reinforce that MbL provides a meaningful avenue for such skill development.

Statistical analysis further confirmed that the improvement in the experimental class was significant, strengthening the claim that MbL is more effective than conventional approaches. This finding echoes international evidence. For example, Kim and Park (2025) reported that incorporating MbL into South Korea's national science curriculum led to a 15% increase in students' SPS scores. Similarly, Bao (2020) emphasized that strategies promoting active engagement and conceptual modeling lead to greater learning gains across diverse educational contexts.

Beyond cognitive outcomes, MbL also nurtures students' metacognitive awareness. By encouraging learners to reflect on their assumptions and refine their models, MbL develops self-monitoring skills that are essential for scientific inquiry. This resonates with research by Schwarz et al. (2009), who showed that modeling-based approaches promote deeper reflection and conceptual integration. In this study, students in the experimental class were more capable of articulating their reasoning and drawing evidence-based conclusions compared to those in the control group, highlighting the metacognitive benefits of MbL.

Nevertheless, it is important to acknowledge that the successful implementation of MbL depends on several contextual factors. Teachers require adequate training to design effective model-based tasks, and classrooms must be equipped with resources to support experimentation and model construction. As Rahmawati et al. (2019) note, Indonesian schools often face resource constraints and rigid curricula, which may pose challenges to widespread adoption of MbL. Therefore, while the results of this study affirm the potential of MbL, policymakers and educators must also consider systemic supports such as teacher professional development and curriculum flexibility.

In conclusion, the discussion highlights that the effectiveness of MbL lies in its alignment with the nature of scientific inquiry itself. By engaging students in authentic scientific practices, MbL significantly enhances their SPS compared to conventional teaching. This finding contributes to the growing body of evidence advocating for inquiry- and model-based learning approaches as essential strategies for improving science education outcomes globally. For Indonesia, where international assessments have repeatedly indicated weaknesses in students' science literacy (OECD, 2019; Mullis et al., 2020), MbL represents a promising pathway to better prepare students with the skills needed for STEM fields and lifelong scientific literacy.

CONCLUSION

Fundamental Finding: Based on the results of data analysis and discussion, it can be concluded that the implementation of the Modeling-based Learning (MbL) approach significantly improves students' science process skills (SPS). The homogeneity test results indicated that the data were normally distributed (Sig. > 0.05), allowing for valid statistical testing. The paired sample t-test on pre-test and post-test scores confirmed a significant improvement in SPS in the experimental class compared to the control class. Furthermore, the average N-Gain score of the experimental class was 0.8 (high category), while the control class only reached 0.5 (medium category). These findings demonstrate that MbL is more effective in enhancing SPS than conventional teaching methods. **Implication:** The results highlight the importance of adopting innovative pedagogical models such as MbL in science classrooms. By actively engaging students in constructing, testing, and revising scientific models, teachers can foster deeper understanding, critical thinking, and problem-solving skills, which are essential for preparing students to meet the demands of 21st-century STEM education. Thus, MbL can serve as an alternative instructional strategy to strengthen science education in secondary schools. **Limitation:** This study was conducted with a relatively small sample size of two intact classes, which may limit the generalizability of the findings. In addition, the implementation of MbL requires teachers who are well-trained in model-based pedagogy and adequate learning resources, both of which may not be equally available in all schools. Time constraints within the curriculum may also pose challenges for widespread application of MbL. **Future Research:** Future studies should explore the long-term effects of MbL on different aspects of scientific literacy, including students' attitudes, motivation, and metacognitive skills. Comparative studies across different educational levels and subject areas would also provide broader insights into the applicability of MbL. Furthermore, research that integrates MbL with digital tools and simulations could offer promising directions for enhancing science learning in technology-rich environments.

AUTHOR CONTRIBUTIONS

Firza Farahdiba Daeng contributed to the conceptual framework, research design, and drafting of the manuscript. **Dea Ramadhana Zsa Zsa Alifah** was involved in methodology development, data collection, and data analysis. **Budi Jatmiko** contributed to supervision, validation, and critical review of the manuscript. **Zainul Arifin Imam Supardi** handled project administration. **Hanan Zaki Alhusni** resource management, **Nina Fajriyah Citra** handled manuscript editing. All authors have read and approved the final version of this manuscript and agree to be accountable for all aspects of the work.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital tools, including AI-based technologies, as support in the research and writing stages of this article. Specifically, Mendeley was employed for reference management and citation formatting, SPSS assisted with statistical analysis of the research data, and ChatGPT (OpenAI) was used as a writing assistant for language refinement and structuring of the manuscript. All outputs generated with digital assistance were critically reviewed, validated, and revised by the authors to ensure academic rigor and ethical standards were upheld. The final responsibility for the content of the manuscript rests entirely with the authors.

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***Firza Farahdiba Daeng (Corresponding Author)**
Postgraduaste Physics Education Department, Universitas Negeri Surbaya
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: 24031635010@mhs.unesa.ac.id

Dea Ramadhana Zsa Zsa Alifah
Postgraduaste Physics Education Department, Universitas Negeri Surbaya
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: 24031635006@mhs.unesa.ac.id

Budi Jatmiko
Postgraduaste Physics Education Department, Universitas Negeri Surbaya
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: budijatmiko@unesa.ac.id

Zainul Arifin Imam Supardi
Postgraduaste Physics Education Department, Universitas Negeri Surbaya
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: zainularifin@unesa.ac.id

Hanan Zaki Alhusni
Postgraduaste Physics Education Department, Universitas Negeri Surbaya
Jl. Ketintang, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231
Email: hanan.20068@unesa.ac.id

Nina Fajriyah Citra
Master of Education in Digital Learning, Monash University
Wellington Rd, Clayton VIC 3800, Australia
Email: ncit0004@student.monash.edu