

The Effectiveness of the STEM-PjBL Model on the Critical Thinking Ability of Elementary School Students on Natural Resources Materials

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Abstract: Elementary school students' critical thinking skills in science learning on the topic of natural resources have not yet developed optimally because instruction tends to rely on conventional Student Worksheets (LKS) and provides limited opportunities for contextual learning. This research sought to evaluate how the STEM-Project Based Learning (STEM-PjBL) model—implemented through a project where students created natural batik dyes—enhances elementary school students' critical thinking skills regarding natural resources. The study adopted a quantitative approach, utilizing a quasi-experimental method structured around a One-Group Pretest-Posttest Design. The sample consisted of 26 fifth-grade students from a public elementary school in Cirebon City, Indonesia, selected through purposive sampling. Data were collected using a critical thinking skills test, a student response questionnaire, and classroom observations. The data were analyzed utilizing the Shapiro-Wilk test, the Wilcoxon Signed Rank Test, N-Gain analysis, and descriptive statistics. The results showed that the mean pretest score increased from 77.02 to 81.54 on the posttest. The Wilcoxon Signed Rank Test demonstrated a statistically significant difference, showing a significance value of 0.001 ($p < 0.05$), indicating that the model yielded a highly consistent and uniform improvement across the sample. However, the overall N-Gain score was 0.20 (20%), which belongs to the low category, suggesting that while the positive impact of the model was statistically robust, the short-term duration of the intervention limited the total magnitude of the score increase.

Keywords: Critical Thinking; Natural Resources; PjBL; Science Learning; STEM

Introduction

Natural resources have a very important role for human life and other living things, so their management must be carried out in a way that preserves them (Feng et al., 2023). The preservation of natural resources is carried out by utilizing natural resources wisely, protecting and preserving the environment, reforesting or ecosystem restoration, managing natural resources sustainably, and increasing public awareness and participation so that natural resources remain available and the ecosystem remains balanced. However, unwise

management can lead to environmental damage (Huo & Peng, 2023). Excessive exploitation of natural resources has led to forest destruction, land degradation, water pollution, and declining ecosystem quality. As a result, the capacity of natural resources to support long-term development is decreasing (Boretti & Rosa, 2019). Therefore, wise management of natural resources is key to ensuring the sustainability of human life and other living things in the future. Today's education is expected to equip learners with the knowledge and competencies necessary to become qualified human resources capable of addressing the challenges of the 21st century

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(Bogdány et al., 2025). Education within the era of Society 5.0 requires being oriented towards developing students' potential holistically to achieve 21st century competencies, which are often formulated as the 5Cs: Critical Thinking, Creativity, Communication, Collaboration, and Character (Kain et al., 2024). At the elementary school level, education serves as a foundation for developing students' ways of thinking. One of the skills that must be developed is critical thinking, which refers to the process of active thinking to gain deep understanding (Medranda-Morales et al., 2023). Critical thinking is the embodiment of learning behaviors, especially behaviors related to problem solving.

Developing critical thinking skills is essential for improving students' academic achievement in classroom learning. Students need to be trained in critical thinking because it can help in comparing problems in a classroom and those in the real world (Amani & Mkimbili, 2025). At the elementary school level, science learning assumes an important role by shaping students' scientific thinking, stimulating their curiosity, and developing their ability to understand natural phenomena through logical and systematic reasoning (Bjerknes et al., 2024). Science learning contains material about natural knowledge that is close to students' lives. *Siswa* is expected to be able to understand this natural science knowledge in everyday life (Muhamad Dah et al., 2024). The urgency of implementing STEM learning in elementary schools is also strengthened by the results of bibliometric studies that show that research on STEM has developed significantly in recent years. This trend indicates the increasing recognition of STEM learning as an educational approach that fosters essential 21st-century skills, including higher-order thinking, innovation, teamwork, and problem-solving from the elementary school level. Observational data showed that in grade V at one of the elementary schools in Cirebon City, the problem in learning science on natural resource materials lies in the lack of optimal understanding of students in depth and applicability. Although students have been able to relate the material to daily life, this understanding is still theoretical and has not been realized through meaningful practical activities.

The learning process is still heavily oriented towards the use of *LKS* (student worksheet) books as the main source. This heavy reliance on rigid worksheets limits learning to passive reading and mechanical answer-finding, which prevents students from engaging with the material at a deeper analytical level. Because these worksheets typically demand rote memorization rather than inquiry, students become less motivated to cultivate advanced critical thinking skills. This condition demonstrated that the implementation of learning still needs to be developed to be more contextual and in line with the demands of learning in the Society 5.0 era. In

line with research (Megahati S & Yuliana, 2025), the standard science learning process remains heavily dominated by the use of textbooks, with the stages of activities beginning with the delivery of material by the teacher and continuing with the provision of practice questions whose answers are available in the textbook. This situation causes students to have limited opportunities to explore, analyze, and develop critical thinking skills optimally. To address this issue, the STEM approach can serve as an alternative method for science learning, as it integrates various disciplines to enhance students' critical thinking skills (Ekayanti et al., 2025). Implementing the STEM approach has the potential to increase student engagement in learning activities and foster a positive scientific attitude (Alim et al., 2025). This approach emphasizes cross-disciplinary integration to develop high-level thinking skills as well as relate learning to real life. One of the advantages of the STEM approach is that the learning process encourages students to cultivate creativity, strengthen collaboration skills, and expand critical thinking abilities (Padmawati et al., 2025). In elementary school science education, the STEM approach can be implemented through contextual activities focused on natural resources. For example, in the natural resource material, students make natural dyes from surrounding plants for *jumputan* batik. This practical activity directly aligns with the traditional cultural principles of Ciwaringin Batik which utilizes local plants for sustainable, natural coloring.

By extracting pigments from local flora just as artisan communities do, students learn foundational science and environmental concepts through hands-on, culturally contextual utilization of natural resources. With this, the STEM approach serves as an effective solution to systematically improve the quality of learning, especially in developing students' critical thinking skills. Thus, an appropriate learning model is needed that supports the effective application of STEM approaches in teaching and learning activities. The STEM approach is more optimally applied through PjBL, a student-centered learning model that effectively develops 21st century skills (Nazip Suratman et al., 2023). PjBL is a learning model designed to provide meaningful learning experiences that advance students' critical thinking skills via targeted problem-solving activities (Syahlan et al., 2023). Learning with this model emphasizes on students' activities to produce products as a form of applying the skills of researching, analyzing, making and presenting products from concepts that have been learned with real experience (Daryanes et al., 2023). The benefits of this approach include helping students grasp scientific concepts of science because students are directly involved in making projects so that students understand problems in science learning (Widowati et al., 2025).

Previous studies have demonstrated that integrating PjBL with the STEM approach in elementary schools positively enhances students' learning outcomes by promoting hands-on learning, strengthening collaboration and communication skills, and creating more engaging and meaningful learning experiences (Pandi et al., 2025). On the other hand, various studies indicate that implementing project-based learning integrated with a STEM approach serves to enhance students' conceptual understanding, critical thinking abilities, and collaboration skills by delivering contextual, practice-based learning experiences (Le et al., 2023). These findings are supported by other research stating that this approach is more effective at developing higher-order thinking skills compared to instruction that relies solely on hands-on practice methods (Oknaryana et al., 2025). Thus, this research is relevant to previous studies that focused on the application of the STEM integrated PjBL model in improving conceptual understanding, collaboration skills, and critical thinking skills of elementary school students. However, there is a research gap because previous research has not specifically examined the influence of the STEM-PjBL approach in science learning on the critical thinking ability of elementary school students on natural resource materials. Most of the research still discusses the application of STEM-PjBL in general in science learning, without specifically examining natural resource materials.

This study was explicitly executed to determine the influence of the innovative STEM-PjBL model on the development of critical thinking skills of elementary school students. Therefore, the formulation of the problem in this study is whether the STEM-PjBL model affects the critical thinking ability of elementary school students. The formulation of the problem is further elaborated into several research questions, namely How effective is the STEM-PjBL model on the critical thinking ability of elementary school students? ; How do students respond to learning using the STEM-PjBL model? How is the implementation of learning using the STEM-PjBL model in the classroom? In line with the formulation of the problem, the purpose of the research is to evaluate the effectiveness of the STEM-PjBL model on the critical thinking skills of elementary school students, assess student responses, and describe the implementation of this model in the classroom.

Method

This research adopted a quantitative approach utilized a quasi-experimental method to analyze the effect of implementing the learning model on students' abilities. The research design utilized is One Group Pretest-Posttest Design, which constitutes an experimental design that involves one group of

subjects with pretest before treatment and posttest after treatment. The sample in this research is grade V students at one of the Cirebon City Elementary Schools which totals 26 students. The sampling technique used is purposive sampling. Data was collected utilized tests (pretest and posttest), questionnaires, and observations. The research design used is illustrated in Table 1.

Table 1. Pretest and Posttest Research Design

Initial Conditions	Treatment	Final Condition
O1	X	O2

Description:

O1: Pretest score (before treatment) to determine students' critical thinking skills.

X: The treatment provided is in the form of the application of a STEM learning model based on Project-Based Learning.

O2: Posttest scores (after treatment) to determine changes or improvements in students' critical thinking skills.

Referring on the research design in Table 1, students' critical thinking skills were measured through the provision of pretests before treatment and posttests after the application of the STEM-PjBL model. For this reason, the data collection instruments in this study include a critical thinking ability test (according to Ennis), student feedback questionnaires, and teaching practice evaluations.

Data analysis

Data analysis within this research was conducted to resolve the initial statement of the problem. The test results will be tested using the normality test, homogeneity test, average test of 2 paired samples using the parametric test, namely the Paired Sample Test (if normal) and the non-parametric test, namely the Wilcoxon Signe Rank Test (if it is abnormal). In addition to being tested using the data above, this study was also tested using N-Gain to see how much the research score increased from before the test and after the test. After that, the results of the questionnaire and observation will be analyzed descriptively.

Normality Test

The normality of the data was assessed utilized the Shapiro-Wilk test, as the study involved fewer than 50 respondents. The decision-making criteria for the normality test are illustrated in Table 2.

Table 2. Normality Test Criteria

Sig. Value.	Remarks
Sig. > 0.05	Normally distributed data
Sig. < 0.05	Data is not normally distributed

Homogeneity Test

A homogeneity test was performed to see if the research data shared equal variances. In this research, homogeneity was assessed utilized Levene's Test in the SPSS software. The criteria for interpreting the homogeneity test outcome are illustrated in Table 3.

Table 3. Homogeneity Test Criteria

Sig. Value	Remarks
Sig. > 0.05	Varians data homogen
Sig. < 0.05	Data variance is not homogeneous

Uji Hypothesis

Since the normality test showed that data lacked normal distribution, validation proceeded with the Wilcoxon Signed-Rank Test. Final benchmarks regarding this hypothesis test are illustrated in Table 4.

Table 4. Hypothesis Test Criteria (Wilcoxon Signed Rank Test)

Nilai Sig.	Verdict
Sig. < 0.05	H ₀ is rejected and H ₁ is accepted
Sig. > 0.05	H ₀ accepted and H ₁ rejected

Analysis N-Gain

N-Gain analysis is utilized to see how much the average score has increased from before the test and after the critical thinking ability test of students. The distribution of N-Gain scores used in this study is presented in Table 5 and the category of interpretation of N-Gain effectiveness in Table 6.

Table 5. N-Gain Score Distribution

N-Gain Value	Category
$g > 0.70$	Height
$0.30 \leq g \leq 0.70$	Medium
$g < 0.30$	Low

Table 6. Category N-Gain

Percentage (%)	Interpretation
< 40	Ineffective
40-55	Less Effective
56-75	Quite Effective
>76	Effective

Result and Discussion

This section presents the findings from scientific investigation metrics concerning how the STEM-PjBL model impacts critical thinking skills among elementary school students studying natural resource materials. The information evaluated comprised the results from the student critical thinking skills test, student response questionnaire, and student activity observation sheets. The analysis was carried out using the normality test, the Wilcoxon Signed Rank Test, the N-Gain analysis, the

descriptive analysis of the questionnaire, and the descriptive analysis of the observation results. The findings of the data analysis are presented in the following tables.

The Influence of the STEM-PjBL Model on Students' Critical Thinking Skills

Before hypothesis testing, the pretest and posttest data underwent specific evaluation for normality using the Shapiro-Wilk test because the number of research samples amounted to 26 students or less than 50 respondents. Normality assessments are performed to determine if the data originates from a normally distributed sample so that the appropriate type of statistical test can be determined.

Table 7. Normality Test Results

Variables	Statistic	df	Sig.
Pretest	0.87	26	0.004
Posttest	0.77	26	0.000

Table 7 presents, specific outcomes from the normality test via Shapiro-Wilk proving that analytical probability for the pretest equals 0.004 while the posttest reaches 0.000. The two significance values are less than 0.05 (Sig. < 0.05), meaning that the compiled pretest along with posttest metrics lack normal distribution. As a result, hypothesis testing shifted toward the Wilcoxon Signed Rank Test, being a mathematical nonparametric test utilized to determine the difference between two paired samples that are not normally distributed.

Table 8. Homogeneity Test Results

Variable	Levene Statistic	df 1	df 2	Say.	Verdict
Pretest-Posttest Results	1.06	1	50	0.30	Homogeneous

Referring on Levene's Test outcomes, the calculated Levene Statistics reached 1.06, whereas the significance value (Sig.) was marked 0.30. Since this significance value exceeded 0.05, the research data were determined to have homogeneous variances.

Table 9. Wilcoxon Signed Rank Test Results

Variable	N	Mean Rank	Sum of Ranks
Negative Ranks	3	9.17	27.50
Positive Ranks	20	12.43	248.50
Ties	3	-	-
Total	26	-	-

Referring to Table 9, it is known that there are 20 students who have increased their grades (positive ranks), 3 students have decreased grades (negative ranks), and 3 students have received fixed grades (ties). Furthermore, data from the Wilcoxon test revealed a

probability score around 0.001 (<0.05) meaning H_0 was rejected and H_1 was accepted. Thus, Consequently, real disparities exist regarding learners' critical thinking skills prior toward following lessons using this STEM-PjBL model. These results show that the application of the STEM-PjBL model has a significant influence on students' critical thinking skills on natural resource materials. The improvement of students' critical thinking skills is supported by the characteristics of the STEM-PjBL model that integrates elements of Science, Technology, Engineering, and Mathematics in each Project Based Learning syntax. The integration provides students with the opportunity to build knowledge through a contextual and problem-solving-centric learning experience. Such findings mirror previous research from (Morris, 2025; Nur & Ikhsan, 2024) which states that project-based STEM learning is able to create an authentic learning experience through real problem solving, so that students become vigorously engaged within procedures of systematic investigation, autonomous decision-making, alongside comprehensive knowledge development which directly stimulates escalating critical thinking skills.

In determining the basic questions, students identify problems related to the use of natural resources as natural dyes through observing and asking questions. The activity represents the characteristics of science, because students build an understanding based on the outcome of observations of the phenomena discovered. Furthermore, in the synthesis of making project designs and compiling schedules, students design work procedures, determine tools and materials, and develop project implementation strategies collaboratively. This stage shows the characteristics of Engineering, as students design solutions to solve the given problems. In monitoring the progress of the project, students carry out the project by using various tools and observing the process and results of making natural dyes. The activity integrates the characteristics of Technology through the use of tools to support the learning process and Science through observation activities, data collection, and analysis of observation results. Furthermore, in the syntax of the results assessment, students compare the results of the project, interpret the observation data, and draw conclusions referring to the evidence obtained. This stage reflects the characteristics of Mathematics, as students use data as a basis in analyzing and evaluating project results. Finally, on the syntax of experience evaluation, students reflect on the learning process, evaluate project results, as well as stating the reasons for the conclusions obtained. That systematic series of activities offers golden opportunities for students to advance traits like offering simple explanations, establishing basic skills, managing to conclude, generating further explanations, plus structuring smart strategies aimed toward successfully solving problems.

The findings of this investigation align with a researchs (Azzahra et al., 2025; De Klerk et al., 2025) which found that the use of STEM-PjBL significantly improved the critical thinking skills of elementary school students compared to conventional learning. This STEM-PjBL model grants active student great spaces to combine science, technology, engineering, and mathematics fundamentals while finishing real projects, accelerating their comprehensive high-level thinking skills beautifully. Such statements align perfectly with matching research of (Raras Setyo Retno et al., 2025), who claims that STEM-focused project work efficiently boosts the analytical thinking skills of primary schoolchildren since pupils are actively engaged in hands-on exploration and practical troubleshooting tasks. Additionally, an extensive meta-analysis demonstrated that Project-Based Learning generates beneficial effects toward advancing critical thinking skills via prioritizing independent student-centered learning alongside delivering practical authentic learning (Ješková et al., 2022; Rasyid et al., 2023). For measuring the precise magnitude of the increase regarding critical thinking skills following the application of the STEM-PjBL model, statistical calculations followed using N-Gain.

Table 10. N-Gain Analysis Results

Variable	Pretest mean	Posttest mean	Average n-gain	Category
Critical thinking skills	77.02	81.54	0.20	Low

Table 10 shows that the mean N-Gain score was 0.20 (20%). According to the N-Gain classification, this value falls within the low category and is considered ineffective referring to the N-Gain effectiveness criteria. However, the Wilcoxon test revealed a statistically significant difference between the pretest and posttest scores. These findings demonstrate that the STEM-PjBL approach exerted a substantial impact on students' critical thinking skills, although the level of improvement remained low. The low N-Gain score can be influenced by several factors, such as the relatively short implementation time, the limited student experience in project-based learning, and the diverse initial abilities of students. At the elementary school level, the adaptation process to STEM-PjBL learning takes a considerable amount of time because students must be accustomed to designing, testing, revising, and evaluating solutions independently or in groups. When students are not yet familiar with the activity, the increase in critical thinking skills tends to be not optimal.

These findings gain clear backing from research (Hu & Guo, 2021; Vega Vermehren, 2025) which states that the development of critical thinking skills through

STEM learning requires an ongoing process so that students have sufficient opportunities to develop optimal high-level thinking skills. In addition, (Kwangmuang et al., 2021; Stuppan et al., 2025) in their literature review explained that the effectiveness of STEM-PjBL on critical thinking skills is influenced by the quality of learning implementation, student characteristics, and the duration of implementation of the learning model in the classroom. Furthermore, to determine the improvement of critical thinking skills in each indicator, an analysis was carried out on the average pretest and posttest scores referring to the critical thinking ability indicators. The findings of the analysis are presented in Figure 1.

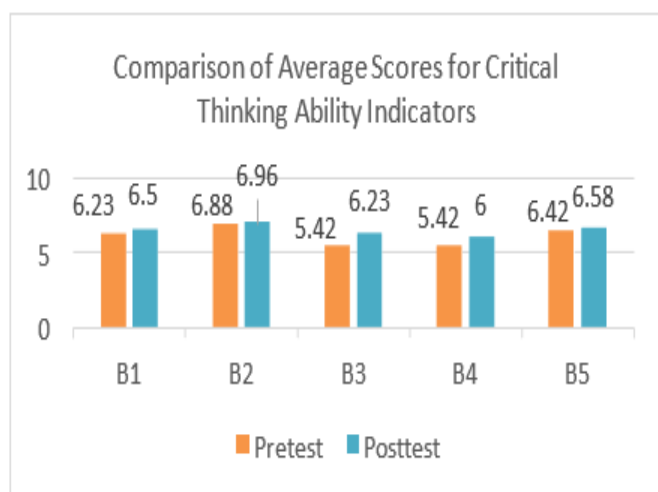


Figure 1. Critical Thinking Ability Indicator Test Data

Description:

- B1: Provide a simple explanation
- B2: Build basic skills
- B3: Summing up
- B4: Provide further explanation
- B5: Strategizing

As illustrated in Figure 1, the average scores for each indicator of students' critical thinking skills increased from the pretest to the posttest. In the pretest, the indicator of building basic skills obtained the highest average score of 6.88, while the indicator concluded and provided further explanation obtained the lowest average score of 5.42. In the posttest, the indicator of building basic skills still had the highest average score of 6.96, while the largest increase in the average score occurred in the concluding indicator, which was from 5.42 to 6.23. Overall, these results show an increase in students' critical thinking skills in each indicator after learning.

Student Response to STEM-PjBL Learning

The student response questionnaire demonstrated that actual deployment of this STEM-PjBL model reached an outstanding average score of 81.40%, safely classified as very good. These results show that students gave a positive response to the learning that has been carried out. The aspect of understanding the material received a good category (80.42%), while the aspect of critical thinking skills (81.25%), involvement in learning (82.44%), and collaboration and responsibility (81.49%) received the category of very good.

Table 11. Student Response Survey Results

Yes	Aspects	Percentage (%)	Category
1.	Understanding of the material	80.42	Good
2.	Critical thinking skills	81.25	Excellent
3.	Engagement in learning	82.44	Excellent
4.	Collaboration and responsibility	81.49	Excellent
	Average	81.40	Excellent

These results show that STEM-PjBL learning is able to actively involve students in the learning process through project activities related to natural resource materials. Through the project of making natural dyes and jumpitan batik, students gain hands-on learning experience so that it is easier to understand the material learned. In addition, students' involvement in discussion, problem-solving, choice-making tasks throughout the project also fosters the advancement of analytical reasoning capabilities. The high percentage of collaboration and responsibility elements similarly show that active students can successfully work together within peer groups to complete each assigned project. Overall, the results of the questionnaire show that the application of the STEM-PjBL model received positive responses from students and was able to create a meaningful learning experience on natural resource materials. The present study corroborates previous research by (Guo et al., 2020; Nguyễn et al., 2025) which shows that STEM-PjBL learning received a positive response from students because it was able to increase engagement, creativity, and critical thinking skills during the learning process (Ananda et al., 2023). Similar results were found by (Lesman et al., 2023); (Dibyantini et al., 2023) who stated that STEM-PjBL learning can increase student learning motivation and engagement because it provides a meaningful and contextual learning experience.

Implementation of STEM-PjBL Learning**Figure 3.** Implementation of STEM PjBL Learning

The results of the observation show that all stages of STEM-PjBL learning can be carried out well. Students are able to identify the problem of natural resource pollution, discuss determining natural dye materials, compile project work steps, carry out the manufacture of natural dyes and batik jumputan, and present the results of the project that has been made. At the implementation project stage, students were seen actively working together, preparing tools and materials, recording the results of activities, and identifying obstacles that arise during the project creation process. These activities reflect the emergence of indicators of critical thinking skills such as analyzing problems, evaluating information, and determining solutions to the problems faced. The active involvement of students during learning supports the theory that STEM-PjBL is an approach capable of developing 21st century skills because students learn through real experience and authentic problem-solving. This mirrors a study by (Pratami et al., 2024; Sánchez-García & Reyes-de-Cózar, 2025) proving that Project-Based Learning successfully enhances active learning activities alongside complex critical thinking skills among elementary school students via active immersion throughout their problem-solving process. Similar results were found by (Qahfi et al., 2024; Syukri et al., 2021) who clarified that project-based learning offers opportunities for students to build critical thinking skills through investigation, collaboration, and reflection on the learning outcomes that have been carried out. In addition to the observation results, the implementation of learning is also supported by the results of student LKPD in each STEM-PjBL syntax. The LKPD analysis is used to see the

achievement of student activities in participating in each stage of learning.

Table 12. LKPD Results in Each STEM-PjBL Syntax

STEM-PjBL Syntax	Percentage (%)
Determination of fundamental questions	91.67
Design project planning	90
Develop a project schedule	85
Project monitoring	100
Presentation of results	95
Evaluation	90
Average	91.94

From the table above, the results of the LKPD in each STEM-PjBL syntax show a percentage variation in each learning stage. The highest percentage is found in the project monitoring syntax of 100%, while the lowest percentage is found in the project schedule of 85%. Other syntactics, namely the determination of fundamental questions by 91.67%, project planning design by 90%, the presentation of results by 95%, and evaluation by 90%. Overall, the average LKPD result in all syntypes is 91.94%, which shows that students are able to carry out each stage of STEM-PjBL learning consistently from the beginning to the end of the learning process.

Conclusion

The findings of the research show that the application of the STEM-PjBL model has a significant effect on the critical thinking skills of elementary school students on natural resource materials. The findings are supported by data from the Wilcoxon Signed Rank Test proving notable shifts regarding learners' critical thinking skills before and after learning. However, the outcome of the N-Gain analysis of 0.20 or 20% indicates that the improvement of students' critical thinking skills is still in the low category. In addition, student responses to learning showed a very good category with an average percentage of 81.40%, and observation results showed active student involvement during the project-based learning process. Hence, the STEM-PjBL model can be an effective learning alternative to create a contextual, meaningful, and student-centered learning experience in an effort to develop critical thinking skills in elementary school. However, more sustained implementation over a longer period is required to achieve greater enhancement of critical thinking skills.

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Author Contributions

Conceptualization; methodology.; validation; formal analysis; investigation; F. E. K. N.; resources; data curation; writing – original draft preparation; writing – review and editing.; N. T.;

visualization: T. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The author declares no conflict of interest

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