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Effectiveness of STEM Learning Model and Project-Based Learning to Enhance Critical Thinking Skills in Senior High School

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ABSTRACT

STEM and Project-Based Learning (PjBL) learning models have been applied to support 21st-century learning. However, no empirical evidence has been found to reveal the combined effectiveness of the two models. This study aims to determine the effectiveness of STEM, Project-Based Learning (PjBL), and lecture learning models in improving critical thinking skills. The research was conducted at SMA Negeri 8 Ternate City, North Maluku Province, involving 64 students divided into three classes studying Indonesian natural resource management. A concurrent embedded strategy combining quantitative and qualitative data collection was used. Initial test data indicated reliability at 0.76, with normality tests for the STEM model at 0.08, the PjBL model at 0.13, and lecture learning at 0.14, all showing normally distributed data. The homogeneity test showed homogeneous data with a value of 1.097. The balance test using one-way ANOVA indicated balanced initial abilities (Fhitung 2.52 < Ftabel 3.14). Results demonstrated that by applying the STEM and PjBL learning models, students achieved proficiency in critical thinking skills. Final test data, including normality tests, one-way unequal ANOVA, and post-ANOVA tests, showed significant improvement in critical thinking skills. The STEM model and PjBL model were both effective with no significant differences between them, while both differed significantly from the lecture learning model. The results suggest that both STEM and PjBL models are effective in enhancing critical thinking skills. To address the shortcomings of traditional lecture methods, educators should consider integrating STEM and PjBL approaches into their teaching practices.

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1. Introduction

Science and Technology are important and have a crucial role in addressing future issues by enhancing human resources and enhancing the quality of life (Permana, 2016). To effectively address the growing demands of competition in the 21st century, it is imperative to establish a high-quality education system that can sufficiently prepare students for many professional domains (Brookings, 2019). Nevertheless, Indonesia's education system exhibits disparities and often falls short of international benchmarks. The rigidity and ineffectiveness of traditional educational methods worsen the issue, leading to a significant disparity between the goals of education and how it is carried out, (World Bank, 2020).

Contemporary educators must use innovative teaching methods, adjust to current advancements, and provide engaging, purposeful, and pleasurable learning encounters. This contemporary approach contrasts with the conventional, classical, and traditional ways that historically held sway in education. 21st-century learning prioritizes a participatory-centric approach, where students actively engage in their learning and use technology, (Larson & Miller, 2011; Smith, 2018).

STEM Model, incorporating science, technology, engineering, and mathematics, emerges as a pivotal alternative that can prepare students to navigate the complexities of the 21st century (Brookings, 2020) and explore student behavior models (Lou et al., 2011). By implementing the STEM learning model and Project-Based Learning (PjBL), students can develop essential 4C skills: collaboration, communication, creative innovation, and critical thinking. Studies have shown that this teaching approach effectively enhances critical thinking abilities, which are crucial for problem-solving and creativity in contemporary society, (Darling-Hammond et al., 2020; Krajcik & Czerniak., 2018).

In line with this, the PjBL which is not much different from the STEM learning approach because these two lessons are centered on students, is expected to be able to develop students' skills, according to Gear 21st century learning or project-based learning which is project and task-based, can explore the potential of students and can provide meaningful and interesting learning experiences for students (Daryanto & Karim, 2017). Every application of the learning model has a goal, one of which can improve critical thinking skills, and problem-solving is wrong, with mental activity in solving problems, analyzing assumptions, providing rationales, evaluating and making decisions, is very important if someone can apply these aspects then that person has thought critically, besides that they can explain the relationship between the problems discussed based on the appropriate experience they get and relevant, (Saputra, 2020). Implementing the STEM learning model and PjBL, students can develop essential 4C skills: collaboration, communication, creative innovation, and critical thinking. Studies have shown that this teaching approach effectively enhances critical thinking abilities, which are crucial for problem-solving and creativity in contemporary society, (Darling-Hammond et al., 2020; Krajcik & Czerniak., 2018).

According to Gear, students participate in project-oriented activities and tasks in 21st-century learning, sometimes referred to as project-based learning, to realize their potential and get worthwhile and engaging learning experiences (Daryanto & Karim, 2017). The goal of every application of this learning framework is to improve cognitive skills including assessment, decision-making, logical reasoning, problem-solving, analytical thinking, and critical thinking. Its capacity to enable students to use this capacity, participate in critical thinking, and explain how the topics covered relate to their own pertinent experiences is what gives it its significance, (Saputra, 2020).

Despite the benefits of both STEM and the PjBL model, current research highlights some of their shortcomings. According to a study by Wang et al, (2011), the curriculum should include real-world problem-solving to enhance the effectiveness of the STEM Model. Similarly, according to Lou et.al., (2013), PjBL increases student engagement and understanding. In contrast, according to a recent study by Becker and Park., (2011), these challenges can be mitigated by evaluating the effectiveness of STEM (science, technology, engineering, and mathematics) and PjBL (project-based learning) to provide a holistic learning experience that enhances theoretical understanding and real-world application.

The reality in the field based on the results of preliminary observations at SMA N 8 Terernate City on geography teachers, learning activities, especially in the cognitive abilities of students only listen and receive information without going through the process or activities of observing, analyzing, and concluding at the end of the learning process, so that it causes cognitive abilities, especially in critical thinking skills (HOTS) students are not maximally stimulated. Geography learning still looks monotonous (teacher center). Teachers have not stimulated children to hone their critical thinking skills in facing problems and being able to solve problems, the ability to make something new with technological innovation, the ability to speak and write, listen, read, and utilize technological media in learning, or the ability to work together with classmates. Thus, considering the critical thinking skills of students must continue to be trained in a guided and repetitive manner to develop students' mindset. So the purpose of this study is to see the effectiveness of STEM model learning, and the PjBL model and to describe the process and results of the application of the STEM learning model and PjBL Model in class XI IPS at SMA Negeri 8 Ternate City, North Maluku Province.

2. Method

The research design used in this study is a combination research method *(Concurrent model)* is a research procedure where researchers combine quantitative and qualitative data to obtain a comprehensive analysis to answer research problems (figure 1).

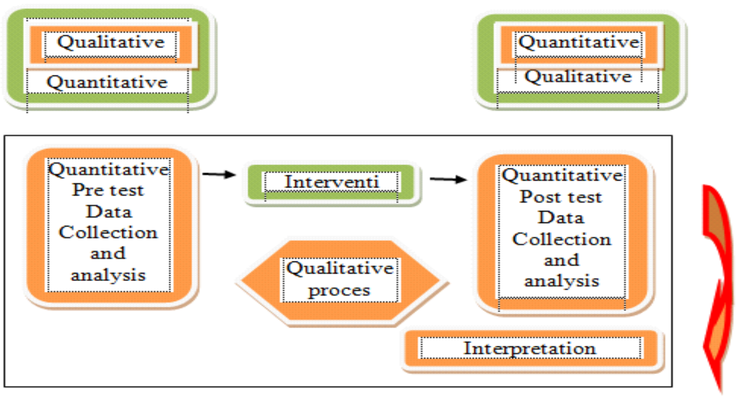

Figure 1. Combination method of *Concurrent embedded strategy* model
Source: (Pane et al., 2022).

Pre-test, treatment, and post-testing are all included in this study. The purpose of a pre-test is to assess patients' cognitive functioning before starting treatment. As part of a prerequisite analysis, the data's homogeneity and normalcy must be confirmed. It also necessitates assessing the question's validity and reliability and the balance assessment using a one-way ANOVA test for uneven cells. The investigation was carried out by researchers Campbell and Stanley (1963); Creswell (2014). The research participants were picked at random by XI IPS 1 and 2 at Ternate's 8th State High School. Twenty students made up the control group, twenty students made up the first experimental group, and twenty students made up the second experimental group. Random assignments were employed by Kerlinger & Lee (2000) to guarantee that each research participant was treated equally.

2.1 Sampling Approach and Frame

This research was conducted at SMA Negeri 8 Ternate City, North Maluku Province by conducting a *pre-test* (initial test), *treatment* (qualitative process), and *post-test* (final test). The implementation of the *pretest* (initial test) is to measure critical thinking skills before *treatment*, test the validity and reliability of the questions, prerequisite test analysis (normality test and data homogeneity test), and balance test using 1-way ANOVA test unequal cells. The samples in this study were taken in 2 classes, which were made into three classes, experiment 1 with a total of 22 students, experiment 2 with a total of 22 students and a control class with a total of 20 students, from 2 classes XI IPS 1 and 2 in SMA Negeri 8 Ternate City, North Maluku Province, which were selected by *simple random sampling* or random, mixed sample in this sampling, the researcher mixes the subjects in the population so that all subjects are considered equal.

2.2 Data Collection Procedure

In this study, there are independent variables (dependent), STEM learning model, *project-based* learning (PjBL) model, and conventional learning as the control class while the dependent variable (independent) is students' critical thinking skills.

2.3 Research Instruments

The instruments used in this study are the observation method of Krits thinking ability and the test instrument of test questions. Observation method of critical thinking skills with a qualitative approach, The research instrument used is an observant sheet of critical thinking skills of students' activities when implementing the application of the learning model can be seen in Table 1.

Table 1. Description Criteria for the Completeness of the Learning Implementation Process of the STEM Model and PJBL Model

Critical thinking skills	Newly Developed	Worth	Cakap	Proficient
Identifying the Topic/problem	Not yet able to understand, identify, and present data	Able to Understand, related to data.	Able to understand, and identify data	Highly Capable Understand, identify and present data.
Research and develop models	Not yet able to find, present information and develop models	Adequate Able to find information related to the topic.	Able to find information and develop models	Highly capable of finding, presenting information and developing models
Determine data relevance and plan tasks	Not yet able to gather relevant information and plan the task	Fairly able to gather information related to the topic	Able to gather relevant information related to the topic.	Very capable of working together to gather relevant information related to the topic
Ask questions and interpret the material and analyze the data again	Not yet able to work together to find solutions, dig deeper, ask questions and analyze data	Moderately able to find solutions to dig deeper, ask questions and analyze data related to the topic	Able to work together to find solutions, dig deeper, ask questions and analyze data	Very Able to work together to find present solution data, dig deeper, ask questions and analyze data

Critical thinking skills	Newly Developed	Worth	Cakap	Proficient
Identify solutions, make explanations in drawing conclusions	Not yet able to find, present the best solution data, and provide conclusions	Sufficiently able to find the best solution, and provide a conclusion	Able to work together to find the best solution, and provide conclusions	Very able to work together to find present the best solution, and provide conclusions
Show solutions and participate in argumentation activities during presentation	Not yet able to cooperate in presenting results, participating and arguing and presenting data.	Fairly able to cooperate in presenting results, participating, arguing	Able to work together to show presentation results, participate in argumentation and Present data	Very Able to cooperate in presenting results, participating, arguing and Presenting data

2.4. Instrument Testing on Test Questions

Validity Test, Validity is a measurement that shows one by one the validity data of an instrument. If one question is declared valid then the question can measure what you want to measure. A test is declared to have content validity if it measures the lesson that is given, (Arikunto, 2018). A valid or valid instrument has high validity, otherwise, a less valid instrument means it has low validity. The formula used to measure the validity of the question is the formula, *product moment.* In this study testing validity using MS. Exel

Reliability Test, Reliability is an instrument that is quite trustworthy from the instrument itself in other words, through this test it is classified as good as a good tool for collecting data. This study uses the internal reliability test or it can be said as data analysis in one test with different instruments or the same instrument. Thus, researchers use calculations with the K-R 20 formula. MS. Exel. Thus in this study, reliability testing was carried out using MS. Exel *for Windows*.

To assess critical thinking skills, the study uses observational techniques and a double-optional questionnaire. We particularly focused on the assessment and growth of critical thinking abilities when we used the learning model. Following therapy, 35 double-choice questions on the final test assess critical thinking skills at three different cognitive stages: connecting and clarifying (C6), analysis and discovery (C4), and interpretation and clarification (C5). The STEM learning model integrates a range of indicators for critical thinking abilities, including defining a problem or topic, gathering information and creating models, evaluating the importance of data and assigning tasks, posing queries, analyzing sources, reassessing data, developing solutions, providing justifications, formulating conclusions, demonstrating solutions, and participating in discussions during presentations. Some examples of the tasks involved in these indicators include setting topics or problems for students to work on, conducting research, organizing discussions and field trips to identify and resolve issues, evaluating the significance of data, setting deadlines for project completion, posing queries, monitoring students' progress throughout the project, identifying the best solutions, and producing thorough reports, (Bell & Park, 2011; Becker, 2010).

2.5. Data Analysis Procedure

In qualitative research, this stage performs qualitative data processing following the analysis technique chosen according to the research. Meanwhile, in quantitative research, at this stage, the researcher processes the data using statistics to test the hypothesis that has been made in the previous stage, (Pane et al., 2022). Testing the effectiveness of the learning model in this study is known based on the output of the critical thinking ability test results and observes sheets in addition to prerequisite analysis testing, hypothesis testing using the 1-way ANOVA test with unequal cells, and continued with multiple comparison testing after the ANOVA test. Testing before treatment there is a normality test and homogeneity test to know how much this study is said to have a homogeneous and normally distributed sample.

3. Results and Discussion

3.1 Pre-Test Stages (Initial Test) Quantitative Research

Data on the results of the initial test (*pre-test*) before the treatment of STEM model learning, PjBL, and lecture learning. Data on the results of the *pre-test* (initial test) of the STEM learning model, PjBL, and Lecture Learning (control class) before carrying out the treatment so that the initial test is important to determine the ability of students. Thus the data on the results of the *pre-test* (final test) can be displayed in Table 2.

Table 2. Initial test result data of STEM, PjBL, and Lecture learning models

Group	N	Min.	Max.	$\bar{X}$	SD
Experiment 1	24	40,0	71	54	8,2
Experiment 2	24	36,4	67,3	50	8,8
Control	20	34,55	67,2	48	10,24

Based on Table 2, it can be concluded that the initial ability of critical thinking of students in the three classes is very diverse where the average value of experimental class 1 = 54 with the acquisition of a minimum value of 40 and a maximum value of 71 with a standard deviation of 8.2 while experimental class 2 with an average value = 50 and with the acquisition of a minimum value of 36 and a maximum value of 67 with a standard deviation of 8.8, then the control class is average = 48 with a minimum value of 34.55 and a maximum value of 67 with a standard deviation of 10.24. With these results, it can be shown in Figure 2.

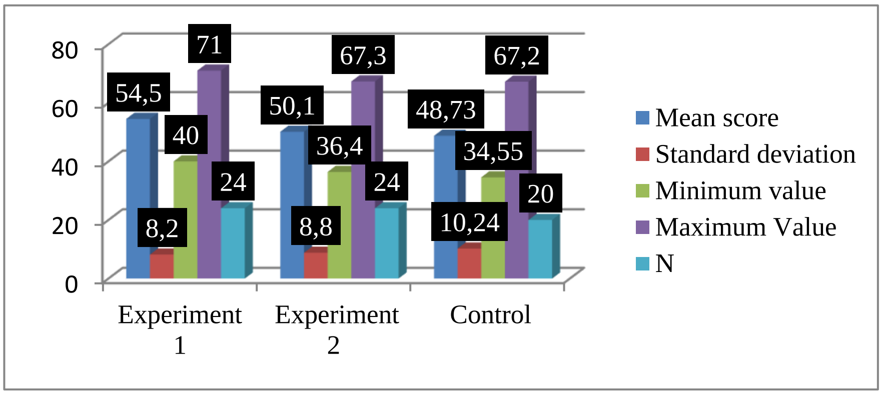

Figure 2. Description of initial test data of STEM, PjBL, and lecture learning models

From the data on the initial test results after being divided into the three groups, the graph above shows that the three experimental groups 1, experiment 2, and the control class have not shown the average results that show the completeness or improvement of students' critical thinking skills.

Validity Test and Reliability Test, In this study 35 questions were made based on a predetermined question grid. Based on the results of the initial test, it is known that the value of the r count is greater than the r table, so the question is said to be valid and reliable. Furthermore, the results of the reliability test can be seen in Table 3.

Table 3. Testing Criteria

Reference Value	*Cronbach's Alpa* Value	Conclusion
0,70	0,767570337	Reliable

Based on the results of 4.7, it can be seen that the reference value is 0.70 and the *Cronbach's Alpa* value is 0.76, so it can be concluded that the 35 questions are said to be reliable and the *test* questions can be used to carry out more detailed research tests can be seen in Table 3.

3.2 Qualitative Research Learning Process Treatment Stages

The application of the STEM learning model revealed that this model can improve critical thinking skills as measured by the criteria for completing learning objectives. To see the achievement of learning during the process of implementing the STEM learning model, a descriptive assessment is given. This was also expressed by Sartika et al., (2022) that the STEM model can improve learning outcomes in the form of students' analytical thinking skills. In addition, the STEM learning model can make students work using logical reasoning in answering logical and complex questions, investigating global issues, and developing solutions to world challenges and problems (Lestari et al., 2021).

The STEM learning model in Experimental Class One is divided into four groups with each theme, a) Group 1 with the theme of understanding the meaning of natural resources and identifying the classification of natural resources. b) Group 2 with the theme of describing the potential and distribution of natural resources and identifying environmentally friendly and sustainable natural resource management. c) Group 3 with the theme of identifying the use of natural resources based on the principle of eco-efficiency and identifying the distribution and management of natural resources. d) Group 4 with the theme of forestry, mining, marine, and tourism resources according to the principles of sustainable development.

Through the theme of each group, the first achievement indicator has been formulated. For the first aspect, identifying the problem or topic given, the results of each group's description are categorized as proficient; students can understand and identify each topic accompanied by data. The second indicator with syntax, research and development models, categorizes each group as proficient because they can search for information and develop models related to each topic by utilizing internet sources and technology media in the form of laptops and cellphones.

Furthermore, the third indicator with syntax, determining the relevance of data and planning the tasks given, categorizing each group as proficient because students can collect relevant information related to each topic, and planning and presenting reports equipped with data by utilizing internet sources and technology media in the form of laptops and mobile phones. Questioning, interpreting, and analyzing data to find missing information is the fourth syntactic accomplishment indication. Because each group can work together to obtain answers, pose more questions, and examine data to spot gaps, this indication classifies them as proficient. Using internet resources, this indicator ultimately provides a findings report that includes a summary of the data in Microsoft Excel.

Global research by Freeman, et. al. (2014) supports the results, showing that cooperative learning settings greatly improve students' ability to absorb and integrate information, resulting in improved problem-solving abilities. Because they were able to work together to discover the best answer, they classified each group as skillful. This approach aligns with the conclusions of Hmelo-Silver et. al. (2007), who highlighted the significance of collaborative problem-solving and reflection in cultivating advanced cognitive abilities. The final achievement indicator, utilizing syntax, signifies the optimal solution and actively engages in argumentation activities by utilizing available evidence. The presentation categorizes each group as proficient due to their ability to collaborate effectively, showcase presentation results, provide supporting evidence, engage in persuasive arguments, and draw relevant conclusions. This includes the selection of effective media (Hendra & Rijal, 2022). Research conducted by Dillenbourg (1999). Provides evidence for the function of technology in enabling collaborative learning and discussion.

The STEM model is very influential at the SMA/MA level; the rest is influenced by other approaches and several other variables. It can also be concluded that the STEM approach is most effective in science-focused areas such as physics and geography. This aligns with the meta-analysis research conducted by Kelly Shrock which concluded that STEM affects 21st-century learning outcomes, including critical thinking skills, creativity, and problem-solving skills. In line with the meta-analysis research conducted by Zeng et al. (2016) in China, their results state that the STEM model is conducive to improving students' higher-order thinking and cognitive abilities, which means that students' experiences have a positive effect on students' abilities and learning outcomes. Similarly, research by Amin & Ibrahim (2022) supports the positive impact of STEM on creative thinking, critical thinking, and problem-solving skills.

Students' critical thinking abilities have been significantly improved by using the STEM learning paradigm, which is in line with earlier study results from many studies conducted all over the globe. Sartika et al. (2022) have shown that holistic STEM-based learning has demonstrated efficacy in enhancing the critical thinking abilities of elementary school pupils. This is consistent with research conducted by Beers et al. (2011), which demonstrates how the STEM learning paradigm fosters critical thinking, problem-solving skills, and adaptability to changing global conditions.

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Moreover, the results align with a worldwide investigation that emphasizes the efficaciousness of the STEM Model in fostering sophisticated cognitive capacities. According to Kelly Shrock's meta-analysis, the STEM Model helps students build 21st-century learning objectives including critical and creative thinking as well as problem-solving abilities. Furthermore, Zeng et.al. (2016) discovered that STEM Model significantly enhances students' cognitive abilities, including critical thinking and problem-solving abilities. These results are consistent with the positive outcomes of the ongoing study.

Additional study demonstrates that the STEM learning paradigm extends beyond traditional lecture-based methods, as shown by STEM students' higher critical thinking proficiency levels. This assertion is bolstered by Bybee (2010), who claims that the STEM Model fosters the application of knowledge to real-world problems, enhancing students' cognitive capacities from the outset. Unlike conventional methods, the STEM approach's use of technology, logical reasoning, and analytical thinking fosters a more engaging and effective learning environment (Prince, 2004).

This research strengthens the worldwide comprehension of the advantages of the STEM Model. The significant enhancement of students' critical thinking abilities underscores the need to incorporate STEM concepts into educational institutions, particularly in poor nations where conventional approaches may be inadequate. Further study should focus on investigating the adaption and application of these models to achieve wider educational enhancements and effectively equip students for the challenges of the 21st century.

The four degrees of accomplishment used to evaluate critical thinking abilities are emerging, competent, proficient, and expert. Experts have validated the validity of this procedure, as shown by empirical validation studies that yielded a reliability rating of 0.767. The starting skills of the groups were found to be evenly distributed, as shown by the balancing test using one-way ANOVA for uneven cell sizes (F observed 2.52 < F essential 3.14). To assess critical thinking abilities in the domain of knowledge, the data collecting techniques used included the use of pre-test and post-test questions. The examination included a combination of multiple choice and essay questions, totaling 35 inquiries about the management of natural resources. Additionally, the test also included observations on the student's performance during the application of the learning model. Table 1 displays the outcomes of the preliminary assessment of critical thinking abilities.

The Application of the PjBL Learning Model Towards Improving Critical Thinking Ability. Implementing the PjBL learning approach has shown significant improvements in students' ability to think critically, which is consistent with study results from throughout the world. The descriptive statistics indicate that students in the PjBL model groups demonstrate proficiency in many measures of critical thinking. Pupils show significant proficiency in several areas, such as theme analysis, issue recognition, information retrieval, conversation-based problem solving, evaluating the significance of the facts, and decision-making and commentary.

This level of proficiency aligns with the findings of worldwide research. Larmer et al. (2015) said that Project-Based Learning enables students to develop problem-solving abilities by actively applying knowledge and working together. Consistent with this, Hmelo-Silver et al. (2007) discovered that problem-based learning fosters profound understanding and enables students to integrate and use their knowledge to tackle intricate problems.

Studies indicate that the PjBL learning model is more efficient than traditional lecture-based methods, as shown by the increased degree of proficiency in critical thinking among students. Thomas, (2000) undertook a comprehensive investigation of pjBL and discovered a consistent enhancement in student involvement and problem-solving proficiency across many educational settings, therefore substantiating this assertion.

Ultimately, the results confirm the global acknowledgment of the effectiveness of Project-based Learning in enhancing critical thinking abilities. The integration of the project-based learning model into educational institutions, particularly in impoverished nations where traditional methods may be insufficient, highlights the substantial enhancement of students' abilities. Additional studies should prioritize the investigation of how these models might be adapted and used to enhance education on a broader scale. The goal is to effectively prepare students to successfully confront the problems of the 21st century.

3.3 Date of Final Test Results (*post-test*) After Treatment of STEM, PjBL, and Lecture Learning Models

Data on *post-test* results (final test) of STEM learning model. *Post Test* Results from Data (Final Test) STEM Learning Model, PjBL, and Cramah Learning (control class) itself is one of the achievements of a teacher in carrying out the process that has been planned and has been carried out so that the final test will bring students to good results (complete), Thus the *Post* Test Results Data (Final Test) can be displayed in Table 2.

Table 2. Data on *post-test* results of STEM, PJBL, and Lecture learning models

Group	N	Min.	Max.	$\bar{x}$	SD
Experiment 1	24	65,7	82,9	77,02	4,9
Experiment 2	24	68,6	82,9	76,19	4,2
Control	20	60	77,14	69,71	5,8

The distribution of *post-test* results of experimental group 1 with a total of 24 students got a minimum score of 65.70 while the maximum score was 82.90, thus the average of the experimental class was 77.02 with a standard deviation of 4.9 after that experimental class 2 with a total of 24 students got a minimum score of 68.60 while the maximum score was 82.90 thus the average of the experimental class was 76.19 with a standard deviation of 4.2 and the last control group with a total of 20 students got a minimum score of 60.00 while the maximum score was 77.14 thus the average of the experimental class was 69.71 with a standard deviation of 5.8. Thus, the results of this final bag can be shown with a graphical description of the final data on the ability to think critically of control group students in Figure 3.

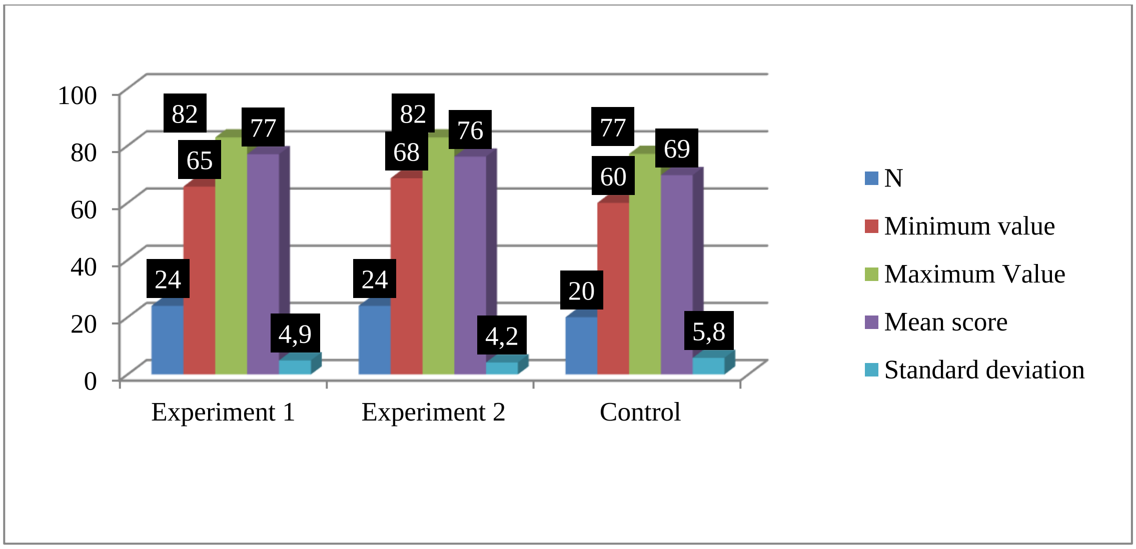

Figure 3. Data on *post-test* results of STEM, PJBL, and Lecture learning models

According to the post-test findings, the STEM and PjBL experimental groups achieved greater scores than the control groups who used the lecture strategy. The mean score for experimental group 1 (STEM) was 77.02, which was significantly higher than the mean score of 76.19 for experimental Group 2 (PjBL). In addition, both experimental groups had lower standard scores, indicating that the test results of the students were more consistent compared to the control group. The control group, which used the lecturing methodology, attained an average score of 69.71 with a standard deviation of 5.8, indicating more variation in student test outcomes. The results indicate that traditional instructional approaches may be comparatively less successful in enhancing critical thinking abilities in comparison to project-based learning or STEM strategies.

Active learning techniques, such as Project-based Learning and Science, Technology, Engineering, and Mathematics, have shown better efficacy in enhancing students' capacity for critical thinking. Research conducted by Darling-Hammond et al. (2020) shows that project-based learning significantly enhances students' problem-solving skills and critical thinking abilities. Moreover, a study done by Krajcik and Czerniak (2018) showed that Project-based Learning enhances the acquisition of problem-solving and critical thinking abilities in students by fostering collaboration and real-world application of knowledge in genuine contexts.

Post-Treatment Research Hypothesis Testing Requirements**.** The research data is calculated and analyzed as an initial step. It should be noted that the research data must first pass the prerequisite test for hypothesis testing. The prerequisite tests are the population normality test and the population variance homogeneity test. Thus, a normality test was carried out on each post-treatment data of the STEM, PjBL, and conventional learning models (Lectures).

Data Normality Test of STEM, PjBL, and Conventional Learning Model Data (Lecture), In this study, the normality test of post-treatment critical thinking ability data can be calculated in each group, based on STEM, PjBL and expository learning models. It is not much different from the normality test of initial ability in the initial test before treatment. Thus, this normality test was carried out using the *Kolmogorov-Smirnov test* with a significance level of α 0.05. A summary of the results of the normality test analysis based on the learning model can be seen in Table 4.

Table 4. Summary of Normality Test Results

Learning Model	N	x̄	Std	D	KS Table	Test Decision	Summary
STEM	24	77,02	4,875	0,08	0,269	H0 Accepted	Normally Distributed
PjBL	24	76,19	4,184	0,13	0,269	H0 Accepted	Normally Distributed
Expository	20	69,71	5,818	0,14	0,269	H0 Accepted	Normally Distributed

The D difference value in each group has a smaller value than the KS table value. Therefore, in each group the D difference value, so it can be said that at the significance level α 0.05, (KS table = 0.269) while the D STEM value = 0, 0.084, D PjBL = 0.133 and D Expository = 0.104, (Table 4). Thus it can be concluded that the data in each sample of the STEM, PjBL, and lecture learning models come from a normally distributed population.

Data Homogeneity Test for STEM, PjBL, and Lecture Learning Models, The homogeneity test has been carried out on the STEM learning model group, PjBL lecture learning. This homogeneity test was conducted using the *Levene test* with a significance level of 0.05. The summary of the homogeneity test results of the STEM, PjBL, and lecture learning models can be seen in Table 5.

Table 5. Summary of Homogeneity Test Results of STEM, PjBL, and Lecture Learning Models

Sample	Levene statistic	df1	df2	sig.	Test Decision	Conclusion
STEM Model					H0 accepted	Homogeneous
PjBL Model	1,4014	2	65	3,13814	H0 accepted	Homogeneous
Expository					H0 accepted	Homogeneous

The value of the three groups based on the calculation of the Levene test with a significance level of α 0.05 is smaller so that H0 is accepted, as can be seen in the results of the Levene statistics = 1.4014 <α 0.05 (3.13814). This means that at a significance level of 0.05, the variance of the three groups based on the STEM PjBL learning model and lecture learning comes from a homogeneous population variance, Table 5.

3.4 Hypothesis Test Results

The data in the study can be tested for its hypothesis based on the analysis prerequisite test that has been carried out. Hypothesis testing is carried out to answer questions in the study. Hypothesis testing is carried out using a one-way ANOVA test of unequal cells, through manual calculations with Excel can be seen in Table 6 and Table 7.

Table 6. Summary of post-treatment data results

Groups	*Count*	*Sum*	*Average*	*Variance*
Model P. STEM (A)	24	1848,571	77,02381	23,76516
P. PjBL model (B)	24	1828,571	76,19048	17,50961
Expository	20	1394,286	69,71429	33,85607

Table 7. Summary of the calculation results of one-way variance analysis of unequal cells

Source of Variant	JK	DB	RJK	F count	F table (α=0.05)	Test Decision
Between Groups	679,08363	2	339,54181			
Error	1592,5850	65	24,501308	13,8581	3,1400	H0 rejected
Total	2272	67				

The results of the analysis revealed the post-treatment results (Table 5). It is known that there are three groups with each group, namely the STEM group, n; 24 obtained a total of 1848.571 and a mean = 77.02381, then the PjBL group with n 24 obtained a total of = 1828.571 and a mean = 76.19048 and the expository group, n 20 and obtained a total of 1491.429 with an average of 69.71429 with each variance value = 23.76516;

17.50961; 33.85607. Then based on Table 14.15 it can be seen that the analysis of variance in one direction of the same cell where there is a sum of squares between groups (JKA) = 679.08363; The value of degrees of freedom (db) = 2 and the number of squares in the JKD group = 1592.5850; while the average number of boxes (RJK) with degrees of freedom (DB) 2 = 339.5418 while the average number of boxes (RJK) with degrees of freedom (DB) 65 = 24.501308. While the Fcount value = 13.8581 and F0.05;2;64 = 3.14, so that FA ϵ DK. One-way Anova DK Unequal Cell for the learning model in this study is {F I F> 3.1400}. Thus H0 is rejected, it is known that there is an interaction between the STEM, PjBL, and expository learning models so further post-anova tests are needed to answer the research hypothesis.

3.5 Further Test of Multiple Comparisons (*Scheffe Test*)

In the analysis of the results of this study, researchers continued to analyze the data with a further test of multiple comparisons (Scheffe Test). This is because the results of the ANOVA calculation provide results that there is interaction or there is a difference between the STEM learning model, PjBL Expository on the critical thinking skills of students. The further test carried out is the comparison test of means between rows (learning model). That is because in this study there are only three columns, so to see more clearly the effectiveness is enough to see the marginal mean value. Before presenting the results of the multiple comparisons test analysis, the marginal means of the data in Table 8 will be presented first.

Table 8. Summary of Cell Mean and Marginal Rate

n	F1	Marginal
Model P. STEM	77,02	72,02
P. PjBL model	76,19	76,19
Expository	69,71	69,71
Marginal Mean		**72,64**

Marginal average, the STEM learning model provides better critical thinking skills results than PjBL and expository learning models (Based on Table 8). It is known that the PjBL learning model provides better results than the expository learning model, as follows. Then continued with the mean comparison test between rows, namely to find out, the most effective learning model among the three models tested to see how much critical thinking skills students have. A summary of the results of the mean comparison test between rows can be seen in Table 9.

Table 9. Summary of Inter-Row Mean Comparison Test Results

No.	Comparison	Fs (Fcount)	Ftable	Description	Test Decision
1	μ_1 vs μ_2	0,340118	6,276284	$F_{obs} < F_{tabel}$	H_0 accepted
2	μ_1 vs μ_3	23,78907	6,276284	$F_{obs} > F_{tabel}$	H_0 is rejected
3	μ_2 vs μ_3	18,67405	6,276284	$F_{obs} > F_{tabel}$	H_0 is rejected

The first comparison was conducted to determine the effectiveness of the STEM and PjBL learning models. In the first comparison, the F value = 0.340118 was obtained so that F ϵ DK with DK = { F I F > F (2) F0.05;2;64}, (Table 8). It can be concluded that. The test decision in the first comparison H0 was accepted, which means that the STEM learning model and the PjBL learning model on critical thinking skills, so it can be concluded that the STEM learning model and the PjBL learning model are not much different because they can provide a good influence in improving students' critical thinking skills. In addition, the STEM approach also involves students in STEM metacognitive activities that have implementations in the classroom that provide opportunities for students to understand the importance of integrating various disciplines and their applications (Lestari et al., 2021). States that STEM can provide students with creative abilities in connecting the four fields of science so that students have deep and dynamic insights in solving related learning materials that have been given (Lestari et al., 2021).

Furthermore, the second comparison was conducted to determine the effectiveness of STEM and Expository learning models. In the second comparison, it is known that FϵDK with the value of F = 23.78907 and DK = {FIF>F (2) F0.05;2;64 }. Thus, H0 in this study was rejected. This means that the STEM learning model provides different effects from the lecture learning model on improving students' critical thinking skills. (Perignat & Buonincontro, 2019 stated that the STEM learning model is more effective than other learning models in improving students' critical thinking skills. This is due to the important role of STEM learning where

STEM is a new pedagogy to respond to what students need in increasing their interest in the world of technology, science, and mathematics (Lestari et al., 2021).

The final comparison was conducted to determine the effectiveness of the PjBL learning model and the expository learning model. In the third comparison, it is known that Fhitung > Ftabel DDK with a value of Ftabel = 18.67405 and DDK = {Ftabel | Ftabel ≥ Ftabel (0.05;2;64)}, hence H0 is rejected. The PjBL learning model has a distinct impact on improving students' critical thinking abilities compared to the expository learning model. Therefore, it may be concluded that the PjBL learning model is more effective compared to the expository learning model. Based on the calculations and research conducted, it is known that students using the PjBL learning paradigm are more effective. The importance of education in today's rapidly evolving world allows educators to choose engaging learning models that may foster students' critical thinking abilities. The project-based learning model is highly effective for classroom learning as it fosters students' knowledge and skills through homework and practical work, enabling students to better understand the given material and enhance their creative thinking and problem-solving abilities (Nurullah, 2021). Furthermore, it enables students to directly integrate or link knowledge and creativity (soft skills) in their learning process, namely the knowledge and skills to plan an activity, solve problems, and communicate the results of their activities or products. Additionally, students master the content of a subject. Students get various learning experiences via the use and development of scientific process skills and attitudes (Djaledje & Nurvita, 2023).

The use of the PjBL learning model without integrating other approaches or methods might result in ineffective learning since not all learning materials can be absorbed by students. Some teachers may not fully comprehend the PjBL learning method, resulting in communication and comprehension challenges for students (Hattie, 2012). Therefore, it is necessary to implement this approach by combining methods and learning strategies. The learning methods are not limited to just one kind but rather consist of many types, including general methods and specialized methods. Common methods, such as the lecture method, question and answer method, and discussion method, provide a structured learning environment (Fisher, 2009). This study used the lecture method, and its findings align with the statement that the lecture method alone may not be sufficient for effective learning.

Bell (2010) argues that project-based learning plays a crucial role in fostering critical thinking and problem-solving abilities in pupils. According to him, combining PjBL with other approaches improves the entire educational experience and results. Furthermore, Blumenfeld et al. (1991) stress the importance of integrating PjBL with collaborative learning methodologies as it may greatly enhance student involvement and comprehension of intricate topics.

Therefore, if the learning technique is used in isolation without being combined with other approaches or methods, it is feasible for learning to occur, but it will not be efficient, and pupils may not be able to grasp all of the learning content. Some educators may lack comprehension of instructional strategies, leading to difficulties in successfully communicating knowledge (Hattie, 2012). Hence, it is essential to implement the strategy including many pedagogical techniques and other cognitive tactics. Effective learning techniques should include a diverse range of approaches to accommodate the distinct learning requirements of individuals (Lusnadi, 2018).

4. Conclusion

This research uncovers noteworthy data that demonstrate the positive impact of using STEM and PjBL learning models on students' critical thinking abilities. These results provide essential insights for educators globally. The ANOVA test findings demonstrated substantial disparities between STEM and PjBL learning models in comparison to lecture learning, with both models exhibiting greater efficacy. This research makes a worldwide contribution by offering educators help in selecting successful strategies to enhance students' critical thinking abilities. This contribution is highly significant in the context of global issues, such as enhancing the quality of education, cultivating skilled human resources in the age of technology and information, and equipping the younger generation to confront global challenges like technological advancements, the digital economy, and global competition. Nevertheless, this research is flawed due to the inadequate representation of the broader population in the samples and the limitations imposed by time restrictions. To enhance the study, it is advisable to use a more extensive sample, account for additional factors that influence critical thinking abilities, employ a combination of research methodologies, and carry out longitudinal studies to observe the long-lasting impacts.

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References

Amin, M., & Ibrahim, M. (2022). Meta Analisis: Keefektifan STEM Terhadap Kemampuan Berpikir Kreatif Siswa (Meta-Analysis: The Effectiveness of STEM on Students' Creative Thinking Ability). *Journal of Authentic Research on Mathematics Education (JARME)*, *4*(2), 248–262. https://doi.org/10.37058/jarme.v4i2.4844

Arikunto, A. (2010). Research Procedures, A *Practical* Approach. Jakarta: PT Rineka Cipta Jakrta.

Bank, W. (2020). *Four of the biggest problems facing education—and four trends that could make a difference*. https://blogs.worldbank.org

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education: Innovations and Research*, 12(5-6), 23-37.

Beers, S. Z., Buckley, B., & Gertzman, A. (2011). STEM education: Challenges and opportunities. *STEM Education: An Overview*, 3-18.

Bell, S. (2010). Project-Based Learning for the 21st Century: Skills for the Future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, 83(2), 39-43.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, 26(3-4), 369-398.

Brookings. (2019). *Challenges in integrating 21st century skills into education systems*. https://www.brookings.edu

Bybee, R. W. (2010). Advancing STEM Education: A 2020 Vision. *Technology and Engineering Teacher*, 70(1), 30-35.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*. Houghton Mifflin.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97–140. https://eric.ed.gov/?id=EJ1249443

Daryanto, & Karim, S. (2017). *Pembelajaran Abad 21*. https://opac.perpusnas.go.id/DetailOpac.aspx?id=1145389

Dillenbourg, P. (1999). *Collaborative Learning: Cognitive and Computational Approaches*. Elsevier.

Djaledje, A. M., & Nurvita. (2023). *Efektivitas Model Project Based Learning Pada Mata Pelajaran Geografi Di SMA Negeri 8 Kabupaten Sigi. 1*(2), 102–110. https://jurnal.fkip.untad.ac.id/index.php/gt

Fisher, R. (2009). *Creative Dialogue: Talk for Thinking in the Classroom*. Routledge.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410-8415.

Hattie, J. (2012). *Visible Learning for Teachers: Maximizing Impact on Learning*. Routledge.

Hendra, H., & Rijal, A. S. (2022). Penggunaan Media Photography Essay Di MAN 1 Kota Gorontalo. *LAMAHU: Jurnal Pengabdian Masyarakat Terintegrasi*, *1*(1), 24–29. https://doi.org/10.34312/lamahu.v1i1.13597

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42(2), 99-107.

Initiative, G. E. I. (2022). *21st Century Education*. https://globaled.gse.harvard.edu/21st-century-education

Kerlinger, F. N., & Lee, H. B. (2000). *Foundations of behavioral research* (4th ed.). Wadsworth.

Krajcik, J. S., & Czerniak, C. M. (2018). *Teaching science in elementary and middle school classrooms: A project-based approach*. Routledge.

Larmer, J., Mergendoller, J. R., & Boss, S. (2015). *Setting the standard for project-based learning: A proven approach to rigorous classroom instruction*. ASCD.

Larson, R., & Miller, T. (2011). *21st-century skills: Preparing students for their future*. National Education Association.

Lestari, N. A., Eraku, S. S., & Rusiyah, R. (2021). Pengaruh Pembelajaran Berintegrasikan Science, Technology, Engineering, and Mathematics (STEM) Terhadap Hasil Belajar Geografi di SMA Negeri 1 Gorontalo (The Effect of Learning Integrated with Science, Technology, Engineering, and Mathematics (STEM) on Geography Learning Outcomes at SMA Negeri 1 Gorontalo). *Jambura Geo Education Journal*, 2(2), 70–77. https://doi.org/10.34312/jgej.v2i2.11587

Lou, S. J., Liu, Y. H., Shih, R. C., & Tseng, K. H. (2011). The senior high school students' learning behavioral model of STEM in PBL. *International Journal of Technology and Design Education*, *21*(2), 161–183. https://doi.org/10.1007/s10798-010-9112-x.

Lou, S. J., Tsai, H. C., Tseng, K. H., & Shih, R. C. (2013). Effects of Implementing STEM-I Project-Based Learning Activities for Female High School Students. *International Journal of Engineering Education*, 29(2), 391-403.

Lusnadi, H. (2018). Integrating Multiple Learning Methods for Effective Teaching. Journal of Educational Strategies.

Nurullah, M. (2021). Efektivitas Pemanfaatan Model Pembelajaran Project Based Learning di SMA N 10 Banjarmasin (The Effectiveness of the Use of the Project-Based Learning Model at SMA N 10 Banjarmasin). *JPG (Jurnal Pendidikan Geografi)*, 8. https://ppjp.ulm.ac.id/journal/index.php/jpg/article/view/11599

Pane, I., Hadju, V. A., Maghfuroh, L., Akbar, H., Simamora, R. S., Lestari, Z. W., Galih, A. P., Wijayanto, P. W., Waluyo, Uslan, & Aulia, U. (2022). *Desain Penelitian Mixed Method (Mixed Method Research Design)* Editor: Nanda Saputra (Issue November). https://id.singlelogin.re/book/25105538/dba099/desain-penelitian-mixed-method.html

Permana, R., et al. (2024). The effects of project-based learning on students' critical thinking abilities. *Journal of Educational Innovations*, 41(2), 134-148.

Permanasari, A. (2016). STEM Education: Inovasi dalam Pembelajaran Sains (STEM Education: Innovation in Science Learning). *Prosiding Seminar Nasional Pendidikan Sains VI*, 23–34. https://media.neliti.com/media/publications/173124-ID-stem-education-inovasi-dalam-pembelajara.pdf

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223-231.

Saputra, H. (2020). Kemampuan Berfikir Kritis Matematis (Mathematical Critical Thinking Ability). *IAIN Agus Salim*, *2020 - Osf.Io*, *April*, 1–7.

Sartika, S. B., Efendi, N., & Wulandari, F. E. (2022). Efektivitas Pembelajaran IPA Berbasis Etno-STEM dalam Melatihkan Keterampilan Berpikir Analisis (The Effectiveness of Ethno-STEM Based Science Learning in Training Analytical Thinking Skills). *Jurnal Dimensi Pendidikan Dan Pembelajaran*, *10*(1), 1–9. https://doi.org/10.24269/dpp.v10i1.4758

Smith, J. (2018). Innovative teaching methods for the 21st century. *Journal of Education Research*, *92*(3), 112–130.

Thomas, J. W. (2000). A review of research on project-based learning. *Autodesk Foundation*.

Wang, H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM Integration: Teacher Perceptions and Practice. *Journal of Pre-College Engineering Education Research (J-PEER)*, 1(2), 1-13. https://doi.org/10.5703/1288284314636.

Zeng, H., Xie, J., & Tam, V. (2016). A meta-analysis of the effects of STEM education on critical thinking skills. *International Journal of STEM Education*, 3(1), 12-25, https://doi.org/10.1186/s40594-016-0046-z