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The Effect of STEM (Science, Technology, Engineering, and Mathematics) Learning Model on Critical Thinking Ability of Students on Colloid Material

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Abstract

This research focuses on Natural Science learning, especially colloid material, where teaching is still dominated by the lecture method. Learning models that encourage students to make direct observations through experiments are rarely applied. This causes students to be less trained in solving problems, so their critical thinking skills are not optimally developed. This study aims to determine the effect of STEM (Science, Technology, Engineering, and Mathematics) learning model on students' critical thinking skills on colloid material at SMA Negeri 1 Telaga. The research design used was pre-experiment with one group pre-test post-test design. The research sample consisted of 29 students selected by census/total sampling. Data collection was done through critical thinking skills test. The results showed that the average percentage of students' critical thinking skills in the pre-test was 46.11%, which was in the medium category, and in the post-test it increased to 83%, which was in the very high category. This shows that the STEM learning model can improve students' understanding and critical thinking skills. The statistical test shows a significance value of 0.000 < 0.05, which means H1 is accepted and H0 is rejected. Thus, it can be concluded that the STEM learning model has a positive influence on students' critical thinking skills.

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1. INTRODUCTION

Education in the era of globalization shows rapid development and has an important role in the development and survival of the nation. Education is something that is dynamic so that it always demands continuous improvement. Education as a learning process aims to develop all the potential that exists in students optimally both cognitive, affective, and psychomotor. The overhaul in the world of education is carried out with the aim that the existing system can be useful in the formation of Indonesian human beings as a whole (Tangio et al., 2021). Education is a crucial component of the process and plays a major role in enhancing the quality of human resources, which are the primary driver of national growth. Human resources with critical thinking skills are particularly important for addressing the problems and challenges brought about by globalization (Apriyani et al., 2017).

Learning is a process that aids pupils in gaining knowledge according to their requirements. It is described as an attempt to shape a person's feelings, mind, and soul so they can learn what they want to learn. More precisely, learning is the process by which the instructor develops each student's potential and range of skills, including critical thinking, creativity, knowledge construction, problem-solving, and content mastery (Angga et al.,

2022). This is reinforced by Rizal Masdul (2018),Learning is a process of educational engagement that aims to motivate students to actively participate and provide them the tools they need to modify their behavior through experiences. Since they equip students to adapt, think critically, and negotiate the complexity of a world that is changing quickly, these abilities are crucial for development in the twenty-first century.

In order to create new ideas and theories regarding the nature of matter, its structure, changes in materials, and the rules and principles governing these changes, chemistry, a part of natural science (IPA), investigates natural phenomena and varied events through observations and experiments. Chemistry topics are procedural, abstract, and concrete, and learning and applying them successfully requires a firm grasp of them (Warahmah et al., 2021).

The interaction of a number of important components, including as the teaching and learning process, students, laboratory technicians, instructor competency, and available resources, is directly related to the study of chemistry. Effective communication between teachers and students is essential to a successful learning experience. To actively involve students in the learning process, teachers must be creative in their instruction. But in reality, chemistry instruction in schools is frequently still conducted in a traditional way, with a teacher-centered approach rather than a student-centered one (Kristaliningtyas et al., 2018).

One of the chemistry subjects that students frequently struggle to understand is colloids. Students find it challenging to properly understand this subject because there are many concepts that must be committed to memory. Students have a harder time grasping colloidal materials because of their intricacy and abstract notions (Rumape et al., 2023).

One essential life skill is critical thinking. It empowers people to make responsible, well-informed decisions that affect their lives. One can develop critical thinking abilities to become self-reliant, adaptable to difficulties, and able to reason through choices. For pupils to correctly grasp information, critical thinking is crucial. Critically thinking students are able to recognize problems, evaluate pertinent data, and reach the right conclusions in order to resolve them (Saeng et al., 2021).

Accuracy, relevance, reasonability, and thoroughness are all components of critical thinking. It is employed in problem analysis, information synthesis, generalization, application, interpretation, assessment of hypotheses and supporting arguments, problem solving, and decision making. This way of thinking guarantees a thorough and deliberate approach to comprehending and resolving a variety of challenges (Alisia, 2019).

Learning about science, especially chemistry, is strongly related to technology, which is essential to improving and supporting people's lives. This partnership makes it easier to incorporate science, technology, engineering, and mathematics (STEM) into chemistry education. In addition to gaining technological expertise by reading, writing, observing, and conducting experiments, STEM education helps students improve critical thinking abilities. This method gives pupils the skills they need to function in society and solve common issues, especially those pertaining to STEM professions (Ariyatun & Octavianelis, 2020). Permanasari, (2016) Since STEM has the ability to build the skills and talents of the next generation and equip them to meet the challenges of the twenty-first century, it is said to be an alternate method to scientific education at the moment.

It has been demonstrated that STEM education improves students' motivation, attitudes, learning interests, and accomplishments. Additionally, it has been noted that STEM education improves pupils' technology literacy and higher-order thinking abilities. It also fosters the growth of pupils' capacity for innovation and invention as well as their problem-solving skills. These abilities are essential for encouraging pupils' creativity and critical thinking while preparing them for obstacles in the future (Davidi et al., 2021).

Research on "The effect of the STEM (Science, Technology, Engineering, and Mathematics) learning model on students' critical thinking skills on colloidal material at SMA Negeri 1 Telaga" is of interest to the writers after reading this explanation.

2. METHOD

Type of Research

This research is a quantitative research. This study used a one group pretest-posttest design involving one group of students who were given a pre-test before treatment and a post-test after treatment without a control class.

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Time and Place of Research

This research was conducted in class XI of SMA Negeri 1 Telaga which is located at Achmad A. Wahab Street, Mongolato Village, Telaga District, Gorontalo Regency, Gorontalo Province. This research was conducted in the 2024/2025 academic year.

Target/Subjects of Research

The research subjects were students of class XI IPA SMA Negeri 1 Telaga, totaling 29 students.

Research variables

This study has two variables, namely the independent variable and the dependent variable. Independent variables are variables that affect or cause changes in the dependent variable. The independent variable in this study is the STEM Learning Model while the dependent variable is the variable that is influenced or the result, because of the independent variable. The dependent variable in this study is Critical Thinking Ability.

Procedure

The following methods were used in this study: (1) Pre-Research (Preparation): During this phase, the researcher gets ready all the tools and materials needed to make sure the study goes smoothly, including choosing the study site. (2) Research Implementation: In this phase, the researcher gives the experimental class a pre-test (Initial Test) that includes critical thinking problems. The researcher uses the STEM learning model to apply the learning activities on colloidal material after the pre-test. (3) Research End: In this last phase, the investigator examines the information gathered from the study sample, talks about the results, and makes inferences.

Instruments and Data Collection Techniques

An essay test with ten questions was the tool utilized in this investigation. Students answered questions from a distributed question sheet in the written portion of the test. The purpose of this test was to collect information about the critical thinking skills of SMA Negeri 1 Telaga class XI students, particularly with reference to colloids.

Data Analysis Technique

The following data analysis methods were employed in this study: (1) Give each question indicator a score before running a validity test. (2) Calculate the test's dependability value. (3) Assess the questions' degree of difficulty. (4) Use critical thinking markers to gauge pupils' proficiency. (5) Test for normalized gain (N-Gain). (6) Test the normality of the data. (7) Perform tests for homogeneity. (8) Conduct the research's hypothesis testing.

Test Reliability

The characteristic that shows a measurement's stability or consistency is called reliability. The Cronbach Alpha formula is frequently used to evaluate the reliability of a test instrument, especially one that takes the form of an essay. The following is the formula for Cronbach Alpha:

$$r11 = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum \sigma_b^2}{\sigma_t^2}\right) \quad (1)$$

Description:

r11 = Instrument Reliability

k = The number of questions or the number of questions

1 = Constant number

$\sum\sigma_b^2$ = Total variance of items

σ_b^2 = Total variance

Table 1. Classification of test reliability coefficient interpretations

Range	Criteria
0,80 < r11 ≤ 1,00	Very High
0,60 < r11 ≤ 0,80	High
0,40 < r11 ≤ 0,60	Fair
0,20 < r11 ≤ 0,40	Low
0,00 < r11 ≤ 0,20	Very Low

(Atika, 2022)

Test Question Difficulty Level

The distribution of 25% easy, 50% medium, and 25% challenging items makes a good question in this study. The percentage of pupils that properly answer a question typically serves as the basis for the formula used to evaluate the questions' level of difficulty. The following formula is used to determine a question's difficulty index:

$$TK = \frac{\text{Mean}}{\text{maximum score}} \quad (2)$$

Description:

TK = Question difficulty level

Mean = Average student score

Maximum Score = Maximum score available on the scoring guidelines

Table 2. Classification of difficulty index

Range	Criteria
0 % – 15 %	Very Difficult
16 % – 30 %	Diffficult
31 % – 70 %	Medium
71 % – 85 %	Easy
86 % – 100 %	Very Easy

(Sari et al., 2020)

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Determining Students' Ability Level Based on Critical Thinking Indicators

Tests that make reference to the elements of critical thinking are used to gauge students' critical thinking abilities. Essay-style questions that have attained five critical thinking indicators are used to assess the development of critical thinking abilities. The following formula is used to determine the overall test score for each indicator:

$$NP=\frac{R}{SM}\times 100\% \quad (3)$$

Description:
NP = Percentage value sought or expected
R = Raw score obtained
SM = Overall maximum score
100 = Fixed number

Table 3. Category of students' critical thinking ability level

Score (%)	Category
81 – 100	Very high
61 – 80	High
41 – 60	Medium
21 – 40	Low
0 – 20	Very low

(Nuraeni, 2019).

Normalized Gain (N-Gain) Test

Analyzing critical thinking abilities by calculating the <g> value to ascertain the degree of variation between pre-test and post-test results.

$$<g> = \frac{\text{post-test value pre-test value}}{\text{maximum value-post-test value}} \quad (4)$$

Table 4. Gain score criteria

Value <g>	Criteria
<g>≥ 0,7	High
0,7 ><g>≥ 0,3	Medium
<g>< 0,3	Low

(Harianto et al., 2017).

Homogeneity Test

The homogeneity test used in this study is the Fisher Test, with the following formula:

$$F = \frac{\text{largest variance}}{\text{smallest variance}} \quad (5)$$

(Ode et al., 2017)

The testable statistical hypothesis is stated:

$H_0 : \sigma_1^2 = \sigma_2^2$: The population has a homogeneous variance

$H_1 : \sigma_1^2 \neq \sigma_2^2$: The population has an inhomogeneous variance

Homogeneity testing parameters, namely H_0 can be accepted if $F_{hitung} < F_{tabel}$ and H_0 is not accepted / rejected if $F_{hitung} > F_{tabel}$ with a significant tariff α (0.05) chosen with the free degree (db) of the numerator and the free degree of the denominator of each n-1 in other circumstances H_0 is accepted.

Research Hypothesis Test

The t-test (t-Test: Paired Two Sample for Means) was employed in this investigation to test hypotheses. The formula for the paired sample t-test:

$$t_{hit} = \frac{\bar{D}}{\frac{SD}{\sqrt{n}}} \quad (6)$$

Description:
T_{hit} = calculated t value
$\bar{D}$ = mean difference between measurements 1 and 2
SD = standard deviation of the difference between measurements 1 and 2
n = number of samples
Testing criteria: Testing criteria:
H_0 is rejected or H_1 is accepted if significant < 0.05
H_0 is accepted or H_1 is rejected if significant ≥ 0.05

3. RESULT AND DISCUSSION

3.1. Result

The data used in this study consists of test results that match the components of critical thinking skills. The examinations, which include pretests and posttests, assess five crucial aspects of critical thinking: (1) Strategy and tactic organization; (2) fundamental skill development (basic assistance); (3) inference; (4) advanced clarification (additional explanations); and (5) elementary clarification (simple explanations). To assess the achievement of specific critical thinking criteria, the test results are analyzed. The total number of essay-based test questions was ten. These items were designed to evaluate students' abilities in relation to the five critical thinking markers. By comparing the outcomes of the pretest and posttest, the improvement in the students' critical thinking skills after the intervention is assessed.

Test Reliability Test

The purpose of the reliability test is to evaluate the question instrument's degree of stability or consistency. A dependability coefficient of 0.7255616 was derived from the computation results. A rating of 0.7255616, which is in the high category of dependability categories, shows that the test equipment is dependable

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and capable of measuring the things it is supposed to measure.

Test of Problem Difficulty Level

Analysis of the level of difficulty of the questions in this study was obtained as in the following table:

Table 5. Results of calculation of problem difficulty level

Question Number	Level of difficulty	Classification
1	0,58	Medium
2	0,49	Easy
3	0,44	Medium
4	0,49	Medium
5	0,56	Medium
6	0,47	Medium
7	0,42	Medium
8	0,47	Medium
9	0,44	Medium
10	0,44	Medium

Results of The Average Percentage of Pretest and Posttest on Achievement of Critical Thinking Ability of Students

The results obtained can be seen in the following figure:

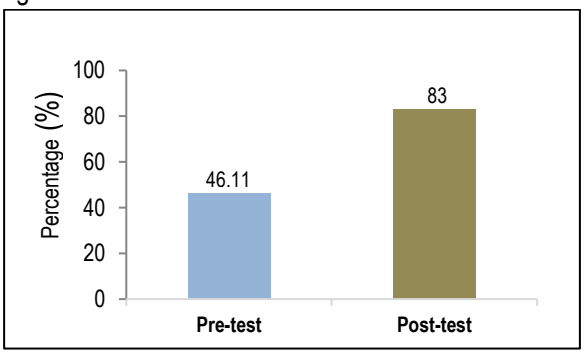

Figure 1. Percentage average total pre-test and post-test critical thinking

Based on Figure 1, it can be seen that the pretest data obtained was 46.11% with a medium category, while the posttest data obtained was 83% with a very high category. This shows that there is an increase in pre-test and post-test scores so that it is said that the STEM learning model is significantly able to improve student understanding and students' critical thinking skills.

Percentage Results of Pretest and Posttest Achievement of Critical Thinking Skills for Each Indicator

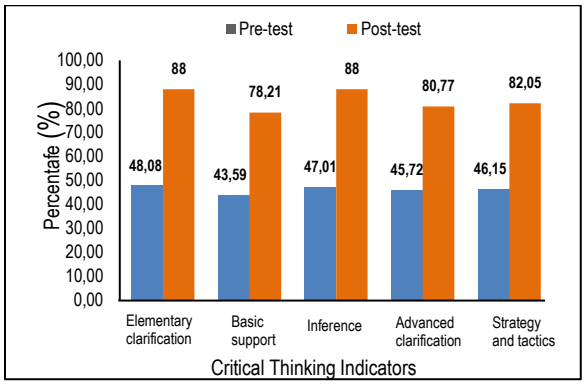

Figure 2. Percentage of pre-test and post-test scores of critical thinking skills for each indicator.

Based on Figure 2, it can be seen that all indicators of critical thinking skills have increased. Indicator 1 (providing simple explanations) and indicator 3 (concluding) experienced the highest increase with an average post-test of 88%. This shows that STEM learning helps students in developing students' understanding and critical thinking.

Normalized Gain (N-Gain) Test

For the normalized Gain (N-Gain) test value on each critical thinking indicator is:

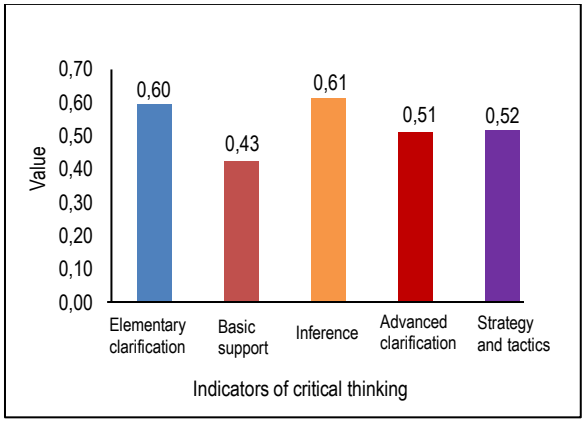

Figure 3. N-Gain value for each indicator

Based on Figure 3, it can be seen that the calculation of n-gain per indicator shows varying results, which illustrates the effectiveness of learning in each aspect. Indicator 1 shows a fairly good improvement, while indicator 3 shows a significant improvement. Indicator 4 and indicator 5 show adequate progress, although they can still be further improved. Indicator 2 showed lower improvement, indicating the need for

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adjustments or improvements in learning methods for that aspect. Overall, despite the variations, the learning has had a positive impact as seen in the increase in scores for each indicator.

Data Normality Test

To ascertain whether or not the collected data is regularly distributed, the normality test is utilized. The Liliefors statistical test is used in this test. At a significance level of 0.05, $L_{count} < L_{table}$ is compared in order to accept or reject H_0.

Table 6 below displays the findings of the test to determine whether the pretest and posttest data were normal.

Table 6. Pre-test and post-test normality test results

Source Data	L_{count}	L_{table}	Test Results
Pre-test	0,1221	0,1614	Normal
Post-test	0,1611	0,1614	Normal

Based on Table 6, it can be seen that the data obtained is normally distributed where the pre-test and post-test results obtained the Lcount value is smaller than the Ltable value.

Homogeneity Test

To ascertain whether the results obtained have a homogeneous variance, the homogeneity test is performed. The homogeneity test can be performed using the Fisher test formula, which declares the data homogeneous at a real level of $\alpha = 0.05$ if $F_{count} < F_{table}$. Table 7 below displays the results of the pretest and posttest homogeneity tests based on the computation:

Table 7. Homogeneity test result

Statistics	Pre-test Dan Post-test	Test Results
F_{count}	1,3593	Homogeneous
F_{table}	1,8821	

Based on table 7, it can be seen that the results of the homogeneity test of pretest and posttest data are said to be homogeneous, where the pre-test and post-test data obtained by F_{count} is smaller than F_{table}.

3.2. Discussion

The purpose of this study is to investigate how students' critical thinking abilities about colloidal material at SMA Negeri 1 Telaga are affected by the STEM Learning Model (Science, Technology, Engineering, and Mathematics). Students from class XI2 made up the study's sample.

Give pupils a pretest before the learning process begins, and then a posttest with the same test questions after they have received treatment. The test instrument used in this study was verified prior to the pretest and posttest to determine whether it could be used or not. Additionally, the Cronbach alpha formula was used to verify the instrument's reliability, yielding r = 0.7255616, suggesting that additional study could make use of the test. This study also evaluated the degree of difficulty of the questions: First question was moderately difficult (0.58), second was moderately difficult (0.49), third was moderately difficult (0.44), fourth was moderately difficult (0.49), fifth was moderately difficult (0.56), sixth was moderately difficult (0.47), seventh was moderately difficult (0.42), eighth was moderately difficult (0.47), ninth was moderately difficult (0.44), and tenth was moderately difficult (0.44). There are ten descriptive or essay-style questions in this study. Five signs of critical thinking are included in the question: (1) Give basic explanations; (2) Develop fundamental skills; (3) Conclude; (4) Provide additional explanations; and (5) Arrange strategies and tactics.

The average percentage of students in class XI2 at SMA Negeri 1 Telaga's overall critical thinking skills on colloidal material, as determined by the pre-test and post-test, significantly improved across all critical thinking indicators, as shown in Figure 1. The average percentage for the pre-test was 46.11%, which is considered moderate. The purpose of this pretest was to evaluate the students' foundational knowledge and level of comfort responding to inquiries. However, the average score on the post-test was 83%, which is considered quite high. The purpose of the posttest was to assess students' critical thinking skills following instruction in the STEM learning model. According to these findings, the posttest's average percentage of critical thinking abilities was higher than the pretest's. While the pre-test measured students' skills before to the implementation of the therapy, the posttest's growth in critical thinking ability is ascribed to the treatment given throughout the learning process. This research is in line with Yasifa et al., (2023), that pupils' comprehension and critical thinking abilities can be enhanced by the STEM approach. As a result, it is advised that educators adopt the STEM approach to teaching as a substitute for traditional methods in science

and other areas. The results of this study support the results of previous studies conducted by Koernelia (2017) and Nailuh et al., (2018) which claim that pupils' critical thinking abilities are significantly impacted by STEM education. In addition, research by Erawati (2019) and Andayani (2020) also discovered that the STEM learning paradigm had an impact on students' level of activity. All things considered, applying the STEM learning approach can help students become more adept at critical thinking.

The indicator of giving straightforward answers in questions 1 and 2 shown a notable improvement from the pre-test to the post-test, as shown in Figure 1. This indicator's average percentage in the pre-test was 48.08%, which is classified as medium; in the post-test, it increased to 87.5%, which is classified as extremely high. This measure shows how well students can respond to inquiries, evaluate claims, and pinpoint the causes of a particular issue. Students' critical thinking abilities in relation to giving straightforward explanations have significantly improved, as seen by the higher post-test score as compared to the pre-test. Thus, it can be said that students' critical thinking abilities in this particular area increased as a result of the STEM learning model's implementation.

From the pre-test to the posttest, there is a noticeable improvement in question 3's sign of developing fundamental skills. The average percentage in the pretest was 43.59%, which was classified as medium; in the post-test, it rose to 78.215%, which was classified as high. This measure shows how well students can reply to questions or comments by offering solutions and citing credible sources to support their arguments. Students' critical thinking abilities in relation to developing foundational skills have significantly improved, as seen by the higher post-test score as compared to the pre-test. Thus, it can be said that the STEM learning model's implementation helped pupils become more adept at this kind of critical thinking.

From the pre-test to the post-test, there is a noticeable improvement in the concluding indications in questions 4, 5, and 6. This indicator's average percentage in the pre-test was 47.01%, which is classified as medium; in the post-test, it rose to 88%, which is classified as extremely high. This metric evaluates students' capacity to solve a particular problem and draw conclusions from their solutions. Students' critical thinking abilities in relation to generating conclusions have significantly improved, as seen by the higher post-test score as compared to the pre-test. Thus, it can be said that students' critical thinking skills in this particular area increased as a result of the STEM learning model's implementation.

From the pre-test to the post-test, there is a noticeable improvement in the indicator of providing further explanations in questions 7, 8, and 9. This indicator's average percentage in the pre-test was 45.72%, which is classified as low; in the post-test, it rose to 80.77%, which is classified as very high. This metric evaluates students' capacity to recognize presumptions and formulate the arguments required to bolster a claim pertaining to a particular issue. Students' critical thinking abilities in providing additional explanations have clearly improved, as seen by the better post-test score as compared to the pre-test. Thus, it can be said that students' critical thinking skills in this area improved as a result of the STEM learning model's implementation.

Question 10's regulating techniques and tactics indicator significantly improved between the pre-test and post-test. This indicator's average percentage in the pretest was 46.15%, which was classified as medium; in the posttest, it rose to 82.05%, which was classified as extremely high. This metric assesses how well students can choose a course of action and figure out how to solve a particular issue. Students' critical thinking abilities in relation to regulating strategies and tactics have clearly improved, as evidenced by the posttest score being higher than the pretest score. Thus, it can be said that students' critical thinking skills in this area improved as a result of using the STEM learning approach.

The N-Gain value test results for each critical thinking indicator are shown in Figure 3. For example, indicator 1 (giving simple explanations) received a score of 0.60 with a moderate category, indicator 2 (building basic skills) received a score of 0.43 with a moderate category, indicator 3 (concluding) received a score of 0.61 with a moderate category, indicator 4 (making further explanations) received a score of 0.51 with a moderate category, and indicator 5 (organizing strategies and tactics) received a score of 0.52 with a moderate category.

In table 6 it can be seen that the results of the normality test in this study are the pre-test results obtained with a value of $L_{count} < L_{table}$ of (0.1221 < 0.1614) while the post-test results with a value of $L_{count} < L_{table}$ of

(0.1611 < 0.1614). From the results of these calculations it can be concluded that the data obtained is normally distributed where $L_{count} < L_{table}$.

In Table 7 it can be seen that the results of the homogeneity test in this study, namely the test results on the pre-test and post-test, obtained $F_{count} < F_{table}$ of 1.3593 < 1.8821, so that the F_{count} obtained is smaller than F_{table}. Based on the test results, it can be concluded that the pre-test and post-test data are homogeneous.

Hypothesis testing from the calculation results for students' critical thinking skills with the t-test (t-Test: Paired Two Sample for Means) obtained P (T ≤ t) two-tail < t Critical one-tail or 1.54 x 10-22 < 1.701 at a significant level of 0.05. This means that there is a significant difference between the pre-test and post-test data. It can be concluded that for the hypothesis H0 is rejected or H1 is accepted, this can be seen in the hypothesis testing criteria. So it can be concluded that the use of the STEM Learning Model has an effect on increasing students' critical thinking skills. This is in line with (Tureni et al., 2021) that there is a discernible change, indicating that the STEM learning paradigm has an impact on students' critical thinking abilities.

4. CONCLUSION

Based on the results of the research that has been conducted, it can be concluded that the application of the STEM (Science, Technology, Engineering, and Mathematics) model has a positive impact on improving students' critical thinking skills. This finding is in line with the research objective which examines how the STEM learning model can develop students' critical thinking skills in the context of 21st century education. The STEM model, which integrates interdisciplinary approaches and problem solving, is proven to encourage students to think logically, analytically and creatively in facing challenges.

However, this study has some limitations, such as the limited sample size of only one school or one group of learners, which could affect the validity of the results. In addition, the relatively short duration of STEM model implementation is also a factor that needs to be considered in strengthening the research results.

For future research, it is recommended that the sample be expanded to different types of schools or different levels of education, and the implementation time of the STEM model be extended to observe the long-term impact on the development of students' critical thinking skills. Future research can also explore other factors that influence the effectiveness of STEM models, such as student motivation or support from teachers in the learning process.

5. ACKNOWLEDGEMENTS

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