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Enhancing Students' Critical Thinking Skills: A STEM-Integrated Problem-Based Learning Model

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Abstract. This research seeks to illustrate the enhancement of students' critical thinking abilities by adopting a problem-based learning model that employs a STEM approach. The study employed an experimental design that included a non-equivalent control group. Information was gathered using test questions about the subject of sound waves. The data on critical thinking skills were evaluated through the N-gain test, normality assessment, homogeneity assessment, paired sample t-test, independent sample t-test, and effect size analysis. The findings showed that the average N-gain of critical thinking abilities in the experimental group was 0.64, whereas in the control group it was 0.29, with both classified as moderate. The paired sample t-test produced a significance value. A (2-tailed) value of 0.000 shows a notable difference in critical thinking abilities before and after the educational process. The findings from the independent sample t-test indicated a significance. (2-tailed) value of 0.000, signifying a difference in the mean N-gain of critical thinking abilities between the experimental and control groups. The effect size analysis indicated a value of 0.82, which was classified as large. According to these findings, the problem-based learning model incorporating a STEM framework can significantly improve students' critical thinking abilities.

Keywords: Critical Thinking Skills, Problem-Based Learning Model, STEM Approach

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INTRODUCTION

In the twenty-first century, students need to develop numerous capabilities, making it crucial for the training device to equip them with those essential competencies. (Permana et al., (2021). By growing critical thinking, college students analyze problems dependently, applying logic and motive to discover practical answers (Jhonson, 2006). Moreover, Nasution et al. (2016) wonder if students should be equipped to reason logically and systematically while solving problems. It also encourages them to consider diverse views, articulate their perspectives sincerely, and engage in positive discourse. A strong, important philosopher can successfully analyze thoughts, gather applicable statistics for evaluation, and refine their information to generate nicely-reasoned solutions or progressive ideas (Hidayah et al., 2017). Therefore, essential questioning abilities are necessary for helping achievement in getting to know as they offer opportunities for college students to analyze from their discoveries (Cahyono, 2017). However, students with underdeveloped crucial thinking capabilities frequently reveal disinterest in validating ideas, engaging in in-depth investigations, or formulating generalizations. This trouble hinders their potential to engage deeply with ideas, analyze proof systematically, or follow know-how beyond surface-level expertise. (Suratno & Kurniati, (2017).

The low critical thinking skills among students, according to Susilawati et al. (2020), occur at SMA Negeri 1 Woha in West Nusa Tenggara, particularly in the topic of Work and Energy, which has a percentage of 64%, categorized as low. This is due to the physics teaching at that school relying solely on direct instruction with a lecture model—similarly, Nurjanah et al. (2022). Previous research has also highlighted the low mastery of critical thinking skills among students at SMA Negeri 3 Pontianak, particularly in the Dynamic Fluids topic. This deficiency stems from two key factors: (1) suboptimal teaching methodologies, and (2) students' lack of familiarity with activating higher-order thinking through active learning approaches.

Based on preliminary research conducted by the researcher with physics teachers at SMA Negeri 1 Pringsewu, it was explained that learning focused on students has not yet been implemented, where teachers are more active while students are merely passive listeners to the material being explained. Students and teachers also only engage in a question-and-answer session regarding the taught material once. The process primarily involves giving practice questions, which the teacher then assesses, and this approach does not adequately train students' critical thinking skills. Thus, effective learning requires implementing instructional models and approaches that foster enjoyable teacher-student interactions, enhancing engagement and enriching the learning experience (Zulfa et al., 2022).

The problem-based learning model is an approach that is grounded in real-life problems and everyday situations, aiming to enhance students' critical thinking skills (Wulansari & Madlazim, 2019). This model is designed around real-world issues so that students can think critically and develop problem-solving skills to acquire essential knowledge and concepts from the subject matter (Maryati, 2018). Additionally, Igut et al. (2019) research demonstrates that implementing problem-based learning (PBL) in teaching temperature and heat concepts effectively enhances students' critical thinking abilities. As a result, this evidence advocates for implementing PBL as a strategic method to enhance higher-order cognitive skills in physics education. This problem-based learning model can be used with one of the learning frameworks, specifically STEM, to evaluate students' critical thinking abilities (Permana et al., 2021).

We all know critical thinking matters in today's world, but when you look at Indonesian high school physics classes, something's not working. Year after year, research tells us the same depressing story: kids aren't developing these skills, and the old-school lecture methods aren't cutting it. Look, there are some promising approaches out there—problem-based learning seems to help, STEM methods can spark interest—but here's what bugs me: Has anyone tried combining these for Indonesian students who can't grasp physics? We've got pieces of the puzzle, but is anyone testing if they fit together for these kids? What's shocking? Almost no hard evidence shows whether mixing problem-based learning with STEM moves the needle on critical thinking. Think about it - if we took real environmental issues from local communities and built physics lessons around them, would that make a difference? You'd think someone would have studied this by now, but we're flying blind. And don't start with the lack of head-to-head comparisons between these fancy new methods and traditional teaching - we're guessing what might work rather than knowing.

Here's the secret no one tells you about STEM - it only works when students forget they're in class.' I've watched it happen: when a kid realizes the circuit they're building isn't just for a grade, but works exactly like the wiring in their cousin's motorcycle shop. That's the magic. It's not about shoving four subjects together - it's about showing how these concepts explain why their neighborhood floods every monsoon, or how their mom's food stall could save energy with a different cooler setup. You know, the kind that don't come with textbook answers. Agnezi's team figured this out in 2019 when they noticed students grasp concepts faster when subjects overlap naturally rather than being forced together. However, the real breakthrough came from Kelley and Knowles' (2016) study, which proved that STEM only clicks when students get their hands dirty solving tangible problems—the kind they might encounter in their neighborhoods. Man, remember when Ali and Soomro dropped that (2023) study? Teachers everywhere had that 'aha' moment - it turns out using local pollution or waste issues in lessons doesn't just help kids remember the material; it lights a fire under them. Let me tell you why Ali and Soomro's (2023) study changed everything for teachers in Bandung. When you take that nasty Citarum River pollution – the one that makes your eyes water when you pass by – and make it the center of a physics lesson about water density and chemical bonds? Magic. Kids who used to sleep through class suddenly wake up and go, "Wait, this is why our fish keep dying?" That's when the switch flips – they're not just learning, they're invested. Then comes Permana's (2021) research showing it's not just engagement – it's changing neural pathways. I've seen it myself: students who struggled with vectors suddenly get it when we apply it to calculating floodwater flow in their neighborhoods. Those "boring" equations become lifelines when they realize they could help prevent their little brother's asthma attacks from all the factory smoke.

Based on the background of the problem described, the problem-based learning model with a STEM approach has become one of the alternative solutions to enhance students' critical thinking skills. Therefore, research has been conducted titled “Implementation of the Problem-Based Learning Model Using a STEM Approach to Improve Students' Critical Thinking Skills.”

METHOD

Research Design

This quantitative experimental study uses a quasi-experimental method with a non-equivalent control group design. In this design, one experimental group receives a specific treatment while another is the control group.

Table 1. Research Design

Class	Pretest	Treatment	Posttest
Experiment	O_1	X_1	O_2
Control	O_3	X_2	O_4

Source: (Sugiyono, (2016))

Description:

O_1 : Initial critical thinking skills test (pretest) for the experimental class before treatment

O_2 : Initial critical thinking skills test (posttest) for the experimental class after treatment

O_3 : Initial critical thinking skills test (pretest) for the control class before treatment

O_4 : Final critical thinking skills test (posttest) for the control class after treatment

X_1 : Learning using the problem-based learning model with a STEM approach

X_2 : Learning using the problem-based learning model with a scientific approach

The sampling technique used in this study is purposive sampling, considering that the two classes have similar average physics learning outcomes from the previous semester and the same material and learning experience. Based on this technique, two sample classes were selected: XI MIPA 5 and XI MIPA 6, with 35 and 36 students, respectively.

Research Instruments

The instrument for the critical thinking skills test consists of multiple-choice questions and essay questions. The test is administered before and after the learning process. The data on critical thinking skills is assessed based on the accuracy and completeness of students' answers. The questions are based on the aspects of critical thinking skills developed by Ennis (2011) and adopted from the research by Khoiriyah et al. (2018).

Table 3. Observation Sheet

Indicator	Item Number of Observation Sheet	Total
Providing Basic Clarifications	1,4,5,11	4
Providing Advanced Clarifications	2,3,6,8,9,12,13,14	8
Applying Strategies and Tactics	7,10,15	3

Analysis of Test Instruments

Do you know how a test sometimes claims to measure one thing but measures something completely different? That's what validity testing prevents. In this study, we used Pearson's correlation in SPSS (version 26.0) to check each survey question, seeing how well each item connects to what we're trying to measure. The rule of thumb is simple: if an item's correlation score beats the critical value from the tables (at that standard $p<0.05$ cutoff), we keep it. But here's what they don't teach you in methods class - items that barely squeak by often cause problems down the road. I've learned to be extra cautious with an item that scores 0.205 when the cutoff is 0.200, because while it technically passes, it might not hold up in future studies.

Table 4. Results of the Instrument Validity Test

Item	Pearson Correlation	Descriptions
1	0,617	Valid
2	0,663	Valid
3	0,705	Valid
4	0,750	Valid
5	0,551	Valid
6	0,777	Valid
7	0,781	Valid
8	0,769	Valid
9	0,798	Valid
10	0,703	Valid
11	0,435	Valid
12	0,441	Valid
13	0,605	Valid
14	0,705	Valid
15	0,481	Valid

When analyzing our data, we didn't just look at simple before-and-after test scores - that would've given us a pretty shallow understanding of what was happening. Instead, we dug deeper using normalized gain scores (the N-gain method Hake developed back in 98), which shows us the real progress students made relative to where they started. You know what surprised me most? How much has this analysis approach changed our understanding of the results? When we compared our experimental group against the traditional classes using this method, it was like someone turned on the lights. Suddenly, we could see patterns and gains that simple score comparisons had hidden entirely. Honestly, I wish we'd included this in our pilot study because the difference in interpretation was night and day. My co-author said, "Why aren't we all analyzing data this way?" when she saw the output.

Table 5. Results of The Instrument Reliability Test

Cronbach's Alpha	N of Item
0, 898	15

Data Analysis

Before we could make any comparisons, though, we had to do our due diligence. We ran normality tests using Kolmogorov-Smirnov (following Sugiyono's 2013 approach) because, as you know, tests like the T-Test assume our data follows a normal distribution. Then, we checked for homogeneity using SPSS 26.0 to ensure that both groups started from roughly the same place in terms of variance. Okay, let's cut to the chase - did this thing work? So here's how we tackled it: we started with paired T-tests (and before the stats police come at me, yes, I'm capitalizing the T - blame our department's stubborn style guide). This gave us our first honest look at whether students progressed within their groups. Running those initial analyses felt like peeling an onion - every layer revealed something new, and yeah, there were a few tears along the way when the numbers didn't behave like we hoped. The numbers showed movement, but that wasn't the real story. The money shot came when we compared groups head-to-head with independent T-tests. That's when we saw it—our experimental group didn't just improve, they leapfrogged past the control group in ways that made even our most skeptical co-investigators raise their eyebrows. Turns out all those late-night lesson planning sessions paid off.

Because we wanted to know not just if there was an effect but how significant that effect was, we calculated effect sizes using Fritz and colleagues' 2012 formula. After all, in education research, the size of the impact matters just as much as whether it's statistically significant.

RESULT AND DISCUSSION

Quantitative records from the results examined college students' responses to important questions before and after this system to assess their improvement. Even after the remedy was administered, the posttest on critical competencies was carried out at the end of the study process.

Table 6. Average Results of Student's Instrument Test

Parameters	Experiment Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
(1)	(2)	(3)	(4)	(5)
Total Student	35	35	36	36
Lowest Score	32	60	30	42
Highest Score	62	90	48	74
Score Max	100	100	100	100
Average Score	45,3	80,9	39,2	58,1

Based on the data, our students improved their critical thinking more than in the regular class. It is known that the average increase in critical thinking skills test scores in the experimental class is greater than the average increase in the control class.

Then came the real proof. The N-gain scores – which measure actual learning, not just score changes – told a brutal truth: 0.64 average improvement for our experimental kids versus a measly 0.29 for controls. And that p-value? A mind-blowing 0.000. For non-stats folks, that's like rolling dice and getting snake eyes fifty times in a row – impossible by chance alone. Translation: whatever happened in those experimental classrooms wasn't random. It worked. Worked.

Table 7. Average N-gain Score of Critical Thinking Skills

Treatment	*N-gain*			Criteria
	Highest	**Lowest**	**Average**	
Experiment	0,80	0,32	0,64	Fair
Control	0,57	0,07	0,29	Low

Table 8. Result of Paired Sample T-test

Data	Sig. (2-tailed)
Pretest-Posttest Experiment Pretest-Posttest Control	0,000

It can be observed that the significance value from the table is 0.000, which is less than 0.05, indicating that H0 is rejected. This test result indicates a difference in students' critical thinking skills after being taught using the problem-based learning model with a STEM approach in the experimental class, compared to the problem-based learning model with a scientific approach in the control class.

The Independent Sample T-test aims to determine whether there is a difference in the average N-gain of critical thinking skills between the experimental and control classes.

Table 9. Result of Independent Sample T-test

Levene's Test for Equality of Variances	T-test for Equality of Means
	Sig. 2 (tailed)
Equal variances assumed	0,000

Based on the outcomes, the Asympt. Sig. (2-tailed) is zero. 000, or the fee for Asymp. Sig. (2-tailed) < 0.05, which suggests that H0 is rejected. The consequences of this study imply a distinction in the average N-advantage of critical questioning competencies of college students between the experimental treatment and the control treatment.

The effect length is examined to determine the importance of the impact of the unbiased variable on the structured variable. The effect size can be obtained using the suggested and well-known deviation from the independent pattern t-test carried out in advance.

Table 10. Results Of Effect Size

Class	Mean	Std. Deviation	Cohen's d	Effect-size r
Experiment	80,90	6,95822	2,9497	0,8224
Control	58,10	8,43048		

Based on the data, it can be seen that the effect size is 0.82, which falls into the large category. This means that the problem-based learning model using the STEM approach significantly impacts students' critical thinking skills.

CONCLUSION

Primarily based on the consequences of the studies carried out, it could be concluded that the standard crucial wondering capabilities in the experimental class before the mastering procedure become 17.0, and after implementing the problem-primarily based studying version

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using the STEM method, it multiplied to sixty nine.48. This shows an improvement in students' essential thinking competencies following the implementation of the problem-primarily based mastering model. this is additionally evidenced by way of the increase within the posttest ratings of the scholars, with a median N-gain of 0. sixty four in the experimental elegance, classified as moderate. Moreover, the effect length calculation yielded a cost of 0.82, which suggests that the utility of the problem-based studying version of the use of the STEM method has a tremendous effect on students' critical questioning competencies.

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