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Assessing Critical Thinking Skills in STEM-PjBL Learning: An Exploration on Wave Topics for High Schools Student

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Abstract: *In the 21st century, students need to master the 4C skills (Critical thinking, Creativity, Communication and Collaboration). One of the skills that is the focus of this research is critical thinking. This study aims to determine the critical thinking skills of high school students after learning with the Science – Technology – Engineering – Mathematics (STEM)- Project Based Learning (PjBL) model. The type of research used is quasi experiment with a posttest only control design research. The sampling technique in this study is cluster random sampling with a sample of 30 students of SMA Negeri 11 Samarinda. The assessment instruments used are in the form of validated Student Worksheets and critical thinking test instruments that have been adapted from previous research. The results of this study show that using the STEM-PjBL model on wave topics can significantly enhance students' critical thinking skills, as seen from the average Student Worksheet score of 83.3%, which falls into the very high category. Additionally, based on the test instrument results, students' abilities are categorized as high, with a score percentage of 81.1%. The STEM-PjBL learning model can be used to train students' critical thinking skills. The critical thinking ability was measured using instruments consisting of Student Worksheets rubrics and tests in the form of post-tests.*
***Keywords**: STEM-PjBL, Critical Thinking, Wave*

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Introduction

Critical thinking skills are one of the key skills that students must possess in the 21st century. In the 21st century, students need to master the 4C skills (critical thinking, creativity, communication and collaboration) (Septikasari & Frasandy, 2018). These skills are needed by students in order to be able to compete in the era of science and technology development (Siswanto, 2018). One of the most important skills in today's era is critical thinking skills (Finissha et al., 2022). Critical thinking is a systematic process of actively and effectively evaluating information through concepts, interpretation, analysis, integration and communication as a means of solving problems (Nafiah & Suyanto, 2014 & Dwyer et al., 2014). In addition, critical thinking skills are thinking skills that focus on what to believe and what to do next (Khoiriyah et al., 2018 & Ashidiq et al., 2024).

Students tend to have difficulty in dealing with problems and in-depth analysis (Yulianto, 2023). This difficulty is caused because there are still many students who have a low level of critical thinking skills (Rosmalinda et al., 2021 & (Wulandari & Warmi, 2022). This is a serious concern because critical thinking skills are very important in preparing students to face real-

world challenges (Rahmasari et al., 2021). In addition, students who have good critical thinking skills tend to be more successful in learning (Sari Nst et al., 2023).

The low critical thinking ability of students is caused by several causal factors. One of them is a less effective teaching method, where many teachers still emphasize memorization methods rather than understanding concepts (Rosmalinda et al., 2021). In addition, learning that is still teacher-centered, makes students not actively participate in learning (Febrianti & Putro Utomo, 2021). Students who are not actively involved in learning tend to have lower critical thinking skills than those who engage in collaboration and discussion (Arif et al., 2020).

The problem of low critical thinking skills is also found in the context of this study, namely in grade XI students at SMAN 11 Samarinda. Based on the results of initial observations and interviews with physics teachers, it is known that the learning process is still dominated by lecture methods and minimal active involvement of students in discussion, exploration, and problem-solving activities. The teacher also said that students tend to be passive when faced with questions that demand in-depth analysis or reflective thinking. This shows that students' critical thinking skills are still not developed optimally, so this problem is relevant and real in the population that is the subject of this study.

One of the solutions to overcome this problem is to implement STEM-PjBL (Science, technology, engineering, mathematics – project based learning)-based learning-based learning. This model not only encourages students to learn actively but can also integrate various disciplines relevant to daily life (Safitri et al., 2023). Project-based learning can improve students' critical thinking skills as they have to plan, execute and evaluate the projects they create (Rehani & Mustofa, 2023). Thus, the application of the STEM-PjBL model is expected to be able to improve students' critical thinking skills in wave material.

Several previous studies have shown that the application of project-based learning models (PjBL), especially those integrated with STEM approaches, has a positive impact on students' critical thinking skills. There is a significant influence of the application of the PjBL model in improving students' critical thinking skills (Virijai et al., 2023). Project-based learning has also been shown to be effective in developing critical thinking skills (Sutria et al., 2023). The application of the PjBL model combined with the STEM approach to physics learning has a positive impact on students' critical thinking skills (Mahombar et al., 2023). Furthermore, most students showed an improvement in critical thinking skills after participating in learning using the STEM-PjBL model (Mabrurah et al., 2023). It was also found that learning with the STEM-PjBL model can significantly improve pretest and post-test results (Allanta & Puspita, 2021). STEM-based learning also makes a positive contribution to the development of critical thinking skills (Ashidiq et al., 2024). In addition, STEM approaches in general have been proven to be able to improve students' critical thinking skills through learning activities that emphasize exploration, analysis, and problem-solving (Khoiriyah et al., 2018).

The purpose of this study is to describe the category of critical thinking skills of high school students in STEM-PjBL-based physics learning, especially in wave materials, based on the results of the analysis of SW rubrics and critical thinking test instruments. This research is important because critical thinking skills are one of the essential competencies of the 21st century that must be possessed by students, especially in facing global challenges in the era of the industrial revolution 4.0 and society 5.0. By integrating the STEM-PjBL learning model in physics learning, it is hoped that students will not only master physics concepts, but also be able to think logically, analytically, and reflexively in solving contextual problems.

Based on the background that has been explained, the formulation of the problem of this research is:

1. What are the categories of critical thinking skills of high school students in STEM-PjBL-based physics learning on wave material based on the student worksheet rubric?
2. What are the categories of critical thinking skills of high school students in STEM-PjBL-based physics learning on wave material based on critical thinking test instruments?

Method

This study uses a quantitative approach. This study uses a quasi experiment type of research with a posttest only control design (Sugiyono, 2013). The design of this study aims to determine the ability of students after being treated in the form of STEM-PjBL (Science, Technology, Engineering, and Mathematics – Project Based Learning) based learning in the subject of Physics, especially in wave material for high school students. This research was conducted at SMA 11 Samarinda with a research sample of class XI-Physics 2 with a total of 30 students. The research process was carried out for 3 meetings, where each meeting lasted for 5 hours of lessons. The research schedule can be seen in table 1.

Table 1. Research Schedule

Lesson Hours	STEM-PjBL Syntax	Activity
1	Reflection	Brief explanation of vibration and wave matter
2	Reflection	Answering reflection questions on SW
3	Research	Gather information and watch an introductory video
4	Research	Explore the concept of waves by answering questions on the SW
5	Research	Explore the understanding of the melde experiment by answering questions on the SW
6	Discovery	Identify what is not yet known on the project to be worked on
7	Application	Stringing experimental tools
8	Application	Stringing experimental tools
9	Application	Retrieve experiment data 1
10	Application	Retrieve experiment data 1
11	Application	Retrieve experiment data 2
12	Application	Retrieve experiment data 2
13	Communication	Group presentations
14	Communication	Group presentations
15	Communication	Post-test work

The data collection technique used in this study uses a test technique. Tests are a measuring tool that will be used to measure students' critical thinking skills (Sembiring et al., 2023). In this study, there are two measuring tools to measure students' critical thinking skills. The first is student worksheet with an assessment rubric that is adjusted to critical thinking indicators and adjusted to the STEM-PjBL syntax which is done in groups, and the second is a post test in the form of 8 multiple-choice questions and 2 description questions that are done individually and given to students after doing STEM-PjBL-based learning. Each question is adjusted to the critical thinking ability indicator with a total of 10 questions which can be seen in table 2.

Table 2. Indicators of critical thinking

No	Indicators of critical thinking	Learning outcomes	Question number
1	Interpretation	Students can conceptually explain the relationship between frequency, wavelength, and wave propagation speed	2

No	Indicators of critical thinking	Learning outcomes	Question number
2	Analysis	Students can analyze the relationship between frequency, period, rope length, load mass, wavelength and wave propagation speed	3, 4, 6
		Students can analyze images to explain wave phenomena	5
3	Inference	Students can deduce the results of the experiment	9
4	Evaluation	Students can compare the results of the experiment with the theory that has been learned	10
5	Explanation	Student can define waves	1
		Students can distinguish between types of waves	7
6	Self-regulation	Students can design tools and conduct experiments	8

The following is the formula used to calculate the presentation of critical thinking skills in each student :

$$NP = \frac{R}{SM} \times 100\%$$

Information
NP : Percent value sought or expected
R : the raw score obtained by the student
SM : the ideal maximum score of the test in question

$$\text{Average} = \frac{\text{total student score}}{\text{number of student}}$$

Table 3. Critical Thinking Skills Category

No	Value range (%)	Category
1	$81{,}25 < X \leq 100$	Very high
2	$71{,}50 < X \leq 81{,}25$	Tall
3	$62{,}50 < X \leq 71{,}50$	Keep
4	$43{,}75 < X \leq 62{,}50$	Low
5	$0 < X \leq 43{,}75$	Very low

(Ermayanti & Sulisworo, 2016)

Results and Discussion

Result

1. Assessment through Worksheet and Its Rubrics

The Student Worksheets (SW) used in this study are STEM-PjBL based and are designed to encourage students to develop critical thinking skills through project completion that is integrated with science, technology, engineering, and mathematics concepts. The assessment of SW was carried out using rubrics compiled based on indicators of critical thinking ability, namely: interpretation, analysis, inference, evaluation, explanation, and self-regulation. This SW consists of 41 essay questions that are done in groups. In the learning activity, students are asked to answer a series of questions that have been adjusted to the indicators of critical thinking ability, such as analyzing information, drawing conclusions, evaluating experimental data, and explaining the results of observations. The questions are structured to guide students to understand the concept of waves through Melde's experiment.

In addition, students were also tasked with designing and creating simple tools for Melde's experiments with readily available materials. After conducting the experiment, students presented their work, including the process of making the tool, the data obtained, and the interpretation of the results based on wave concepts and predetermined critical thinking indicators. The results of the SW assessment are presented in figure 1 below.

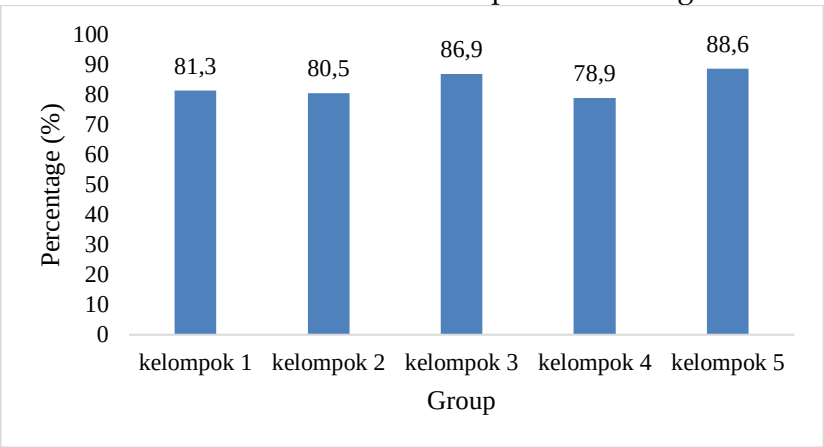


Figure 1. Student Worksheet Assessment Results Per Group

Based on the results of the SW assessment, it can be seen that the SW score of students is in the range of 78.9% to 88.6%. If categorized into the ability to think critically, this value is classified as "high" and "very high". The average results of the SW assessment can be seen in table 4.

Table 4. Average SW Assessment Results Per Group

	N	Minimum	Maximum	Mean	Std. Deviation
Persentasi	5	78.90	92.90	83.3800	5.63359
Valid N (listwise)	5				

Based on the data in table 4, it can be concluded that the average SW assessment is 83.38% with the category of critical thinking ability which is very high.

2. Assessment through Test

This Post-Test is carried out at the end of the research meeting to determine the critical thinking skills of students after learning with the STEM-PjBL model. This Post-Test consists of 10 questions containing 8 multiple choices and 2 essays. The results of the Post-Test assessment are presented in the following figure 2.

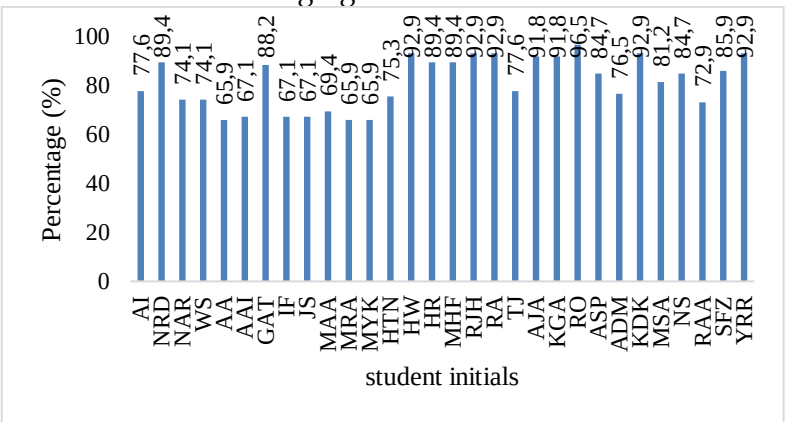


Figure 2. Post-test Assessment Results Per Individual

Based on the results of *the Post-Test* assessment, it can be seen that the student's SW score is in the range of 65.9% to 92.9% which if categorized into critical thinking skills, this score is classified as "moderate" to "very high". The average results of the post-test assessment can be seen in table 5

Table 5. Average Post-Test Assessment Results Individual

	N	Minimum	Maximum	Mean	Std. Deviation
Persentasi	30	65.90	96.50	81.1333	10.39049
Valid N (listwise)	30				

Based on the data in table 5, it can be concluded that the average post-test assessment is 81.1% with the category of critical thinking ability which is high.

Discussion

This research was carried out during 3 meetings with a total of 15 hours of lessons. At the first meeting, students are given brief material on vibration and waves as an introduction because they have never studied it before. After that, they were divided into five groups and each group worked on a Student Worksheet (SW) designed to guide the understanding of wave concepts as well as design simple projects based on STEM-PjBL. In the second meeting, students began to make tools or models according to the wave theme and collected data from the results of the experiment for analysis. The third meeting was filled with a presentation of project results by each group to practice scientific communication and teamwork, then ended with an individual post-test to measure understanding after participating in learning.

1. Group Critical Thinking Skills

The Student Worksheet (SW) in this study was done in groups, with a total of five groups. Each group consists of six students who work together to complete the assigned task. The SW used is an SW based on the STEM Project-Based Learning (STEM-PjBL) approach, which has been designed in such a way to match the syntax or learning stages in the model. The STEM-PjBL syntax listed in the SW includes the stages of Reflection, Research, Discovery, Application, and Communication. Each stage is designed to guide learners through a structured learning process, from understanding concepts to communicating the results of the experiment.

In the process of working on it, students actively discuss and exchange ideas with their group members to find the most appropriate answer. Each group was given the same tools and materials to create a simple melde experiment tool. This experiment was carried out using simple tools and materials, including plastic jars as containers, dynamos as a source of vibration, batteries as a power source, switches, and ropes as wave propagation media. All tool assembly is carried out independently by students based on the instructions listed in the SW and according to the direction from the teacher.

Figure 3. Project Activity Group 1

During the process of working as shown in figure 3, there is a natural division of tasks among the group members. Some students were in charge of writing answers to the SW and

recording the results of observations. Meanwhile, the other members prepare tools and materials, connect the cables between the dynamo, batteries, and switches, and make sure all the components are properly connected. There are also students who hold and adjust the position of the tool, especially in adjusting the rope tension so that the experiment can show the stationary wave pattern optimally. This activity shows the active involvement of students in the learning process. They engage in group discussions to understand the basic concepts of stationary waves, analyze the results of experiments, and solve problems that arise during the assembly and observation process

Based on the results of the analysis of SW carried out by students in groups, it is known that students' critical thinking skills show high to very high achievements. The assessment was carried out using rubrics compiled based on 6 critical thinking indicators, namely Interpretation, Analysis, Inference, Evaluation, Explanation, and Self-Regulation. Each student's answer is assessed based on the rubric on a scale of 1–3 for each indicator. The data that has been obtained is then analyzed using the help of SPSS software through descriptive analysis to determine the mean, minimum, maximum, and standard deviation values. The results of the analysis are then classified into the category of critical thinking skills, thus providing a more objective picture of the level of mastery of students in critical thinking during learning activities. Each indicator is used to assess the extent to which students are able to understand, process, and reflect on the information obtained during the activity process.

The results of the assessment showed that group 1 obtained a score of 81.3%, group 2 of 80.5%, group 3 of 86.9%, group 4 of 78.9%, and group 5 of 88.6%. Based on the criteria for assessing critical thinking skills, groups 2 and 4 are included in the high category, while groups 1, 3, and 5 are included in the very high category. On average, the achievement of students' critical thinking skills in working on the SW is 83.38%, which is included in the very high category.

The results of this study show that students' critical thinking skills through STEM-PjBL-based SW work activities are in the very high category. This shows that a project-based learning model combined with a STEM approach is able to provide space for students to develop analytical skills, evaluation, and decision-making collaboratively. These findings are in line with the results of research that show that the PjBL model has a significant effect on improving students' critical and creative thinking skills (Virijai et al., 2023). Alignment is also seen in the results of other studies that state that the application of the STEM-PjBL learning model has a positive impact on students' critical and creative thinking skills (Sutria et al., 2023; Mahombar et al., 2023). Therefore, it can be concluded that the results of this study reinforce previous evidence that project-based learning with a STEM approach can improve students' critical thinking skills, especially when involved in collaborative activities through SW.

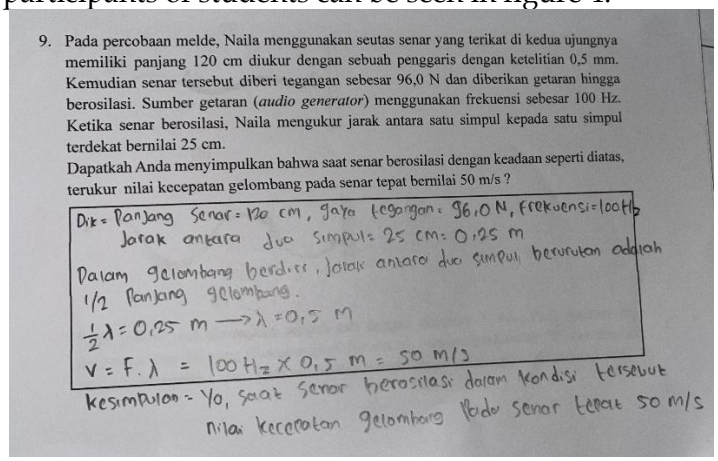
2. Individual Critical Thinking Skills

The post-test in this study was given to measure students' critical thinking skills after participating in STEM-PjBL-based learning on wave material. This *post-test* is designed as an individual evaluation tool to find out the extent to which students are able to apply the concepts that have been learned independently, without the help of groups or other learning resources. All questions in the post-test have been prepared based on the indicators of critical thinking ability, namely Interpretation, Analysis, Inference, Evaluation, Explanation, and Self-Regulation, so that the results obtained reflect the ability to think critically comprehensively (Facione, 2015).

In its implementation, post-tests are done individually without being allowed to discuss, ask teachers, or open any sources of information such as cellphones or notes. Students are given one hour to complete all questions and write the answers directly on the post-test sheet. With this procedure, the post-test results are expected to reflect the students' true critical thinking skills, without intervention from other parties. This condition is certainly more

challenging than when working on SW which is collaborative and helped by the materials available in the SW.

The results of the post-test analysis showed that some questions could be answered very well by students. For example, in question number 2 which asked about wave frequency, all participants answered correctly because this concept had been learned directly in experimental activities and the formula had been taught explicitly. The same thing can also be seen in question number 4 which tests the understanding of the amplitude of deviation and question number 6 which asks about the comparison of wavelengths, both of which were answered well because they had been trained previously through practicum activities. However, there are questions that cause confusion, such as question number 1 which presents a transverse wave image and asks participants to show one wavelength. Many students were fooled because the correct answer did not match their previous understanding of one hill and one valley. Question number 8, especially the third statement, is also a challenge because of its trapping nature and requires the ability to evaluate in depth. The following is one of the answers of post-test participants of students can be seen in figure 4.


9. Pada percobaan melde, Naila menggunakan seutas senar yang terikat di kedua ujungnya memiliki panjang 120 cm diukur dengan sebuah penggaris dengan ketelitian 0,5 mm. Kemudian senar tersebut diberi tegangan sebesar 96,0 N dan diberikan getaran hingga berosilasi. Sumber getaran (*audio generator*) menggunakan frekuensi sebesar 100 Hz. Ketika senar berosilasi, Naila mengukur jarak antara satu simpul kepada satu simpul terdekat bernilai 25 cm.
Dapatkah Anda menyimpulkan bahwa saat senar berosilasi dengan keadaan seperti diatas, terukur nilai kecepatan gelombang pada senar tepat bernilai 50 m/s ?

Dik = Panjang Senar = 120 cm, gaya tegangan = 96,0 N, frekuensi = 100 Hz
Jarak antara dua simpul = 25 cm = 0,25 m
Dalam gelombang berdiri, jarak antara dua simpul berurutan adalah 1/2 Panjang gelombang.
$\frac{1}{2}\lambda = 0{,}25\ m \longrightarrow \lambda = 0{,}5\ m$
$v = F.\lambda = 100\ Hz \times 0{,}5\ m = 50\ m/s$
Kesimpulan = Ya, saat Senar berosilasi dalam kondisi tersebut nilai kecepatan gelombang pada senar tepat 50 m/s

Gambar 4. Students' post-test answers

Overall, students' post-test scores were in the range of 65.9% to 92.9%, with an average of 81.13%, which means that students' critical thinking skills were included in the high category after being given treatment in the form of STEM-PjBL-based learning. When adjusted to the category of critical thinking skills, there are as many as 50% of students who have very high critical thinking skills, 26.6% are classified as high, and 23.3% are classified as moderate. This shows that most students have good critical thinking skills even in individual working conditions.

The high results of the students' post-test are also inseparable from the suitability between the evaluation questions and the learning process that they have undergone, including experimental activities, project discussions, and SW designed based on STEM-PjBL. During the learning process, learners are actively involved in activities that demand understanding of concepts, problem-solving, and critical decision-making. The SW used not only contains practice questions, but also facilitates students to develop critical thinking skills through stages such as data analysis, drawing conclusions, and evaluating experimental results. This creates a continuity between the learning experience and the form of questions in the post-test, which are compiled based on critical thinking indicators. Thus, students have become accustomed to using a critical mindset from the learning stage, so that when faced with post-test questions that require similar skills, they are able to answer better and be more confident. The compatibility between the form of questions, learning activities, and assessment indicators is the main factor in contributing to the overall high achievement of post-test scores.

This research is in line with previous researches. Which shows that after being treated with the STEM-PjBL model, most students are in the critical and very critical category (Mabrurah

et al., 2023). KThis research is in line with previous researches. Which shows that after being treated with the STEM-PjBL model, most students are in the critical and very critical category (Ashidiq et al., 2024). Other research also states that the PjBL-STEM model is able to significantly increase pretest and post-test scores (Allanta & Puspita, 2021).

This shows that the STEM-PjBL learning approach that has been implemented has made a positive contribution to improving students' critical thinking skills. Post-test questions that contain the challenges of analysis, evaluation, and deep reasoning provide space for students to process information critically and systematically.

Conclusion

Based on the results of research and data analysis conducted in class XI Physics 2 at SMAN 11 Samarinda on the application of STEM-PjBL-based learning model to wave materials, it can be concluded that:

1. The critical thinking ability of high school students measured through the student worksheet rubric per group showed a very high category with an average percentage of 83.3%.
2. The critical thinking ability of high school students measured through the critical thinking test instrument carried out individually was in the high category with an average percentage of 81.1%.

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