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Implementation of the REACT Strategy Assisted by PhET Simulation to Improve Critical Thinking Skills on the Mechanical Wave Characteristics Topic

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Abstract. This study examines the improvement of students' critical thinking skills through the REACT Strategy assisted by PhET Simulation. The research employs a quantitative method with a pre-experimental one-group pretest-posttest design. The sample consists of 35 purposively selected 11th-grade students from a high school in Bandung, studying the characteristics of mechanical waves. Instruments include an essay-based critical thinking test (eight questions), and Student Worksheets. Data were analyzed using N-Gain and effect size. Results show that the REACT Strategy with PhET Simulation yielded an N-Gain of 0.52 (medium category). The strategy was also effective in enhancing critical thinking skills, with a high effect size (d = 3.19). In conclusion, implementing the REACT Strategy assisted by PhET Simulation significantly improves students' critical thinking skills in learning.

Keywords: REACT strategy, PhET simulation, critical thinking skills

1. Introduction

Education plays a very important role in improving the quality of a country's human resources [1]. As the world keeps changing, 21st-century skills have become essential for students so they can face the challenges of work and daily life [2]. One of the most important skills to learn is critical thinking, which helps students to analyze, evaluate, and solve problems in a clear and logical way [3].

Several studies have shown that students' critical thinking skills in learning physics are still relatively low. According to research by [4], 55.6% of students had low levels of critical thinking skills, and 30.6% were in the very low category. Other research, [5] also found that only 21% of students had medium critical thinking skills, while 64% were in the low category, and 15% were in the very low category.

These findings are supported by the results of a preliminary study conducted at a senior high school in Bandung. An analysis of the PSAT test results given to students in three Grade XI Science classes, with a total of 96 students, showed that the average score was 62, with a maximum score of 100 and a minimum score of 28. In addition, 68 students (70.83%) did not meet the school's Minimum Mastery Criteria (MMC), while only 28 students (29.17%) were able to meet or exceed the standard. This data indicates that the majority of students are still struggling to understand the tested material.

Furthermore, the results of interviews with physics teachers revealed that students had difficulties in solving physics problems, especially on the topic of mechanical wave characteristics. They struggled to analyze arguments, break down information, and interpret data. In addition, students' interest in physics tended to be low. One of the main reasons was the monotonous teaching method, which still relied heavily on lectures. Limited laboratory facilities and a lack of practical tools also meant that students rarely conducted experiments, leading to less optimal understanding of physics concepts.

This condition is in line with [6] statement, which explains that students have not yet fully acquired 21st-century skills during the learning process at school. This is mainly due to teaching methods that are still teacher-centered and an assessment system that focuses more on memorization rather than the

development of critical thinking skills [7]. A study by Herni also found that students often receive information passively, take notes from the teacher, and complete textbook exercises with limited opportunities to develop their critical thinking skills [8].

The topic of waves is particularly interesting to explore because it is closely related to everyday life activities. Waves have even been used as a central idea in curriculum development by the NRC [9]. A strong understanding of wave concepts can help students grasp related topics such as light, electricity, and magnetism more easily [10]. However, many students struggle to understand wave concepts due to their abstract nature. Some wave-related concepts that students often find difficult include mechanical waves, how waves propagate, the visualization of traveling waves, the principle of superposition, and the concepts of sound and light waves [11]. Research also shows that critical thinking skills have a positive impact on students' conceptual understanding [12].

One strategy that can be used to improve students' critical thinking skills is the REACT learning strategy (Relating, Experiencing, Applying, Cooperating, and Transferring). This strategy emphasizes the connection between the concepts being learned and real-life experiences, while encouraging students to apply these concepts in various relevant contexts. Several studies have shown that experience-based learning and active student engagement can enhance critical thinking skills [13,14]. In addition, research by [15], found that learning strategies that incorporate 21st-century skills can significantly improve both students' learning outcomes and their critical thinking abilities. In addition to using learning strategies that encourage active student participation, choosing the right learning media also plays an important role in the learning process. One alternative medium that can help students understand physics concepts is the Physics Education and Technology (PhET) simulation. This simulation, developed by Katherine Perkins and her team, is available both online and offline. Research by [16] showed that students' post-test scores were higher than their pre-test scores in both the experimental and control groups. However, the improvement in the experimental group was significantly greater. One of the contributing factors to this increase was the use of PhET simulations in the learning process. With the PhET application, students can carry out experiments independently or in groups to solve problems in the laboratory, while receiving quick and accurate feedback from the computer [17]. Therefore, the integration of PhET simulations in the REACT strategy enables students to think critically and understand physics concepts more easily.

Based on this background, the purpose of this study is to implement learning using the REACT strategy supported by the PhET Simulation to improve students' critical thinking skills on the topic of mechanical wave characteristics. This study has several limitations that should be taken into account. First, the subjects in this research were limited to 11th-grade science students at one senior high school in Bandung, so the generalizability of the findings may not fully apply to other levels or regions. Second, the focus of the material was only on the characteristics of mechanical waves, which does not represent the entire scope of physics subjects. Third, the REACT strategy in this study was specifically combined with the PhET simulation, so its effectiveness might differ when applied with other learning media. Lastly, the critical thinking skills assessed were based on specific indicators aligned with the instrument used, meaning other dimensions of critical thinking outside of those indicators were not fully explored.

Despite these limitations, this study is expected to provide both practical and theoretical impacts. Practically, the results of this research can serve as a reference for physics teachers in selecting more interactive and contextual teaching strategies to develop students' critical thinking skills. The REACT strategy supported by the PhET simulation can also be an innovative alternative in technology-based learning, especially for schools with limited laboratory equipment. Theoretically, this research strengthens the study of the effectiveness of experiential learning strategies and active student involvement in enhancing critical thinking skills, as well as broadening the understanding of integrating educational technology into physics instruction. The findings can also serve as a foundation for future research that aims to develop or modify similar teaching strategies for different topics and educational levels.

2. Method

The approach used in this study is quantitative with a pre-experiment design of the One-Group Pretest-Posttest Design type. This study involves one group of participants who are given a pretest before the

treatment and a posttest after the treatment. The population in this study consists of all students in grade XI at Pasundan 3 High School in Bandung, totaling 105 students, which are divided into three classes: XI-1, XI-2, and XI-3, with 35 students in each class. The sample used in this study is class XI IPA 2, consisting of 35 students. The sampling technique used in this study is purposive sampling, which is a sampling technique done intentionally based on specific considerations. In this study's context, the sample was selected based on recommendations from the physics teacher and the suitability of the class for the research objectives, so the chosen class is considered representative to be the research subject. This study was conducted in the even semester of the 2024/2025 academic year, from February 10 to March 3, 2025. The research was conducted at Pasundan 3 High School in Bandung, with a focus on class XI IPA 2 as the research subject.

In this study, the independent variable is the REACT strategy assisted by PhET Simulation. Meanwhile, the dependent variable is the students' critical thinking skills on the topic of mechanical wave characteristics. The theory of critical thinking developed by Robert H. Ennis states that critical thinking is a reasonable and reflective process focused on deciding what to believe or do. In his theory, Ennis identifies several indicators of critical thinking, which include providing basic clarification, providing a basis for decision-making, inferring, giving advanced clarification, and using strategies and tactics. These five indicators serve as the reference for assessing and developing students' critical thinking skills, making them highly relevant for application in a learning process aimed at enhancing students' thinking quality in depth. Instrument is a tool used by researchers to collect data, making the work simpler and producing better results, with data obtained quickly, comprehensively, and in a structured manner, thus making it easier to process [18]. The instruments in this study consist of two types: teaching device instruments and data collection instruments. The teaching device instruments include a teaching module containing learning objectives, learning models, media, learning activities, Student Worksheets (LKPD), evaluation questions, and assessment rubrics, as well as LKPD designed to support active learning and train students' critical thinking skills. Meanwhile, the data collection instrument consists of a critical thinking skills test using essay-type questions that have been validated and pre-tested. These questions were used in the pretest and posttest implementation to measure the improvement of students' critical thinking skills before and after the application of the designed teaching strategy.

The steps in this study consist of three main stages: preparation, implementation, and final stage. In the preparation stage, the researcher conducts a preliminary study both in the field and through literature to formulate the research problem and objectives, design and validate teaching devices and instruments, and then conduct a trial and analysis of the instruments to be used. Next, in the implementation stage, the activities begin with the pretest, followed by the learning process using the REACT strategy assisted by PhET Simulation, and end with the posttest. In the final stage, the researcher analyzes the data, draws conclusions from the results obtained, and prepares a comprehensive research report. The data analysis in this study includes normality tests to determine the type of statistical test to be used, hypothesis testing (t-test) to determine the difference between pretest and posttest scores, N-Gain testing to measure the improvement in critical thinking skills with categories of low, medium, and high, and effect size analysis to determine the magnitude of the effect of the treatment on the improvement of students' critical thinking skills. The data on the improvement of students' critical thinking skills is analyzed using N-Gain calculations. The N-Gain test calculation is done by comparing the pretest and posttest scores using the formula:

$$< g > = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest Score}}. \quad (1)$$

The N-Gain score obtained is then interpreted based on the N-Gain value categories in Table 1.

Tabel 1. Category of indeks N-gain [19].

N-Gain Score	Category
$g > 0.70$	High
$0.30 \leq g \geq 0.70$	Medium
$g < 0.30$	Low

3. Results and Discussion

Based on the data processing results, the N-Gain scores for the overall improvement in students' critical thinking skills were obtained. Below is the graph showing the average pre-test and post-test scores of the students along with the N-Gain scores, as shown in Figure 1.

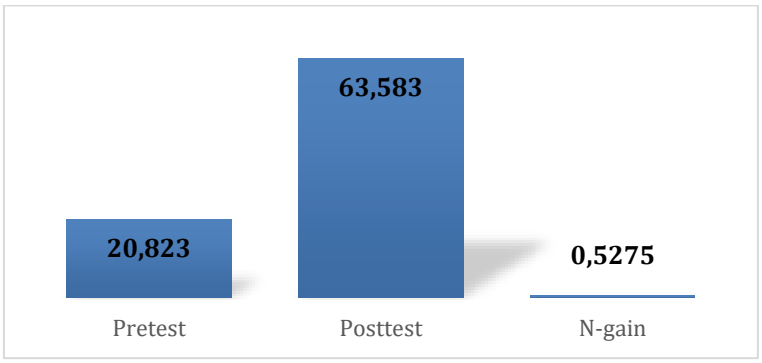


Figure 1. Average scores of pre-test, post-test, and n-gain of students.

Based on Figure 1, the average N-Gain of 0.5275 can be categorized into the medium category. This result indicates that the treatment provided was quite effective in improving the students' abilities. A similar finding was reported by [20] in their study published in the Jurnal Inovasi Pendidikan Kimia (JIPK), Universitas Negeri Semarang. Their research applied the REACT learning strategy to the topic of solubility and solubility product, and found that students' critical thinking skills increased with an N-Gain also falling into the medium category across six indicators. These findings support the current study's results and reinforce the potential of the REACT strategy to foster students' critical thinking skills in various subject areas.The distribution of students' N-Gain scores in each category is shown in Figure 2.

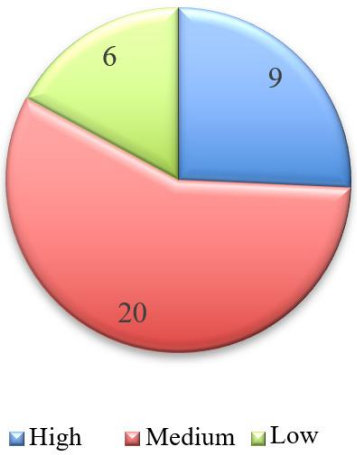


Figure 2. Distribution of students' n-gain scores in each category.

Of the 35 individuals analyzed, the distribution of improvement categories based on the N-Gain values was obtained. A total of 9 individuals, or about 25.7%, showed a high improvement category with N-Gain values greater than 0.70. Meanwhile, the majority of individuals, 20 people or 57.1%, showed improvement in the medium category, with N-Gain values ranging from 0.30 to 0.70. On the other hand, there were 6 individuals, or about 17.1%, who experienced low improvement with N-Gain values below 0.30. These results indicate that, overall, the method or treatment provided was quite effective in improving learning outcomes, as evidenced by more than half of the individuals showing medium improvement and some even achieving high improvement. However, there are still a number of individuals who experienced low improvement, which may be due to various factors such as

differences in initial understanding, level of engagement in the learning process, or other external factors that may influence their learning outcomes.

The findings above are in line with previous research on the REACT learning strategy conducted by [21], which showed an improvement in students' critical thinking skills measured using N-Gain values. The obtained N-Gain value of 0.49 was categorized as medium. This normalized gain score indicates an improvement in students' critical thinking skills. The research conducted by [22] further strengthens the argument that learning supported by PhET Simulation media also leads to an improvement in critical thinking skills. Therefore, it can be concluded that the implementation of the REACT strategy with the aid of PhET Simulation can enhance students' critical thinking skills.

In addition, an analysis was also conducted on the improvement of critical thinking skills in each aspect, which was processed based on the average pretest and posttest scores. The results of these values were calculated using N-Gain and categorized into high, medium, and low categories. The following is the N-Gain value for each aspect of students' critical thinking skills shown in Table 2.

Table 2. N-gain scores for each aspect of critical thinking skills.

Aspect	Pretest	Posttest	N-Gain	Category
Elementary Clarification	38.57	59.29	0.34	Medium
Basic Support	7.14	61.79	0.59	Medium
Advanced Clarification	29.64	61.07	0.45	Medium
Inference	15.71	58.21	0.5	Medium
Strategy And Tactics	22.79	65.50	0.83	High
Overall Average	22.79	65.50	0.54	Medium

The normalized gain score shows an improvement in each aspect of students' critical thinking skills. The diagram of N-Gain values for each aspect is presented in Figure 3.

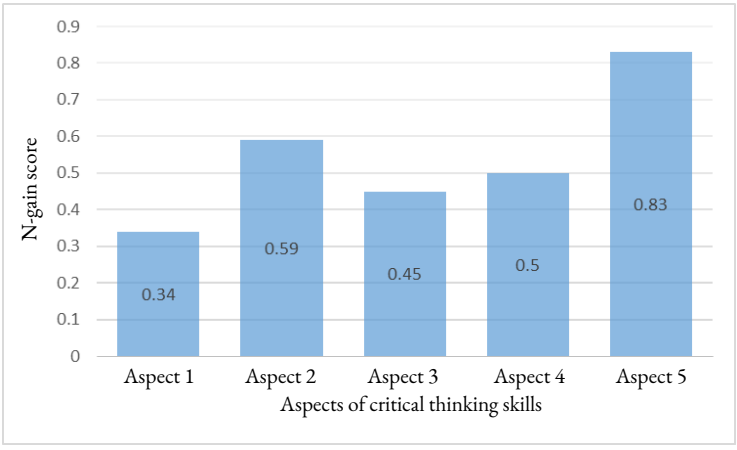


Figure 3. N-Gain score diagram for each aspect of critical thinking skills.

In each aspect, it can be seen that the N-Gain score for the aspect of elementary clarification is 0.34, categorized as Medium. The N-Gain score for the aspect of basic support is 0.59, categorized as Medium. The N-Gain score for the aspect of advanced clarification is 0.45, categorized as Medium, and the N-Gain score for the aspect of inference is 0.50, categorized as Medium. Meanwhile, the N-Gain score for the aspect of strategy and tactics is 0.83, categorized as High.

The aspect of elementary clarification was practiced by students by showing an image related to wave phenomena in everyday life. During the lesson, students were shown a phenomenon of earthquakes and ocean waves. Afterward, students discussed and made explanations for these phenomena. In other words, in this aspect, students were focused on observing and providing explanations independently. In the aspect of elementary clarification, the results of the pretest and posttest produced an N-Gain score of 0.34, which is categorized as Medium. The aspect measured in the question on elementary clarification is question number 1. Below is an excerpt from the question presented in Figure 4.

Soal

1. Bacalah teks dan gambar di bawah ini!

Fenomena Gempa Bumi Cianjur

Gempa yang terjadi di Kabupaten Cianjur pada Senin, 21 November 2022, pukul 13.21 WIB memiliki magnitudo (kekuatan gempa) 5,6 M. Gempa tersebut mengakibatkan banyak korban jiwa dan kerusakan infrastruktur di wilayah tersebut. Pihak BMKG (Badan Meteorologi, Klimatologi, dan Geofisika) mencatat bahwa getaran gempa Cianjur terasa hingga beberapa kota lain

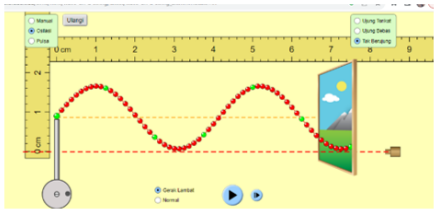
Berdasarkan gambar yang menunjukkan wilayah terdampak gempa Cianjur, beserta informasi tentang magnitudo, kedalaman, dan luas sebaran gempa, daerah mana saja yang merasakan gelombang gempa? Jelaskan bagaimana gelombang gempa dapat merambat hingga ke wilayah yang jauh dari pusat gempa dan apa yang menyebabkan kerusakan pada bangunan di wilayah tersebut!

Figure 4. Excerpt of question number 1.

Figure 4 shows a seismic event phenomenon that occurs on the Earth's surface. Students were given a stimulus in the form of text and a map showing the location and information about the Cianjur earthquake. Students were asked to identify the areas affected by the seismic waves and explain how seismic waves can travel through the ground to distant areas from the epicenter, and how these waves can damage buildings. During the pretest, some students had difficulty answering the question due to a lack of knowledge about explaining the mechanical wave material. However, after the REACT strategy assisted by PhET Simulation was implemented, some students showed improvement in their ability to explain during the posttest.

In the basic support aspect, students build foundational skills for the topic to be studied by being asked to formulate a problem to investigate, and then seek answers to that problem. Afterward, students are asked to make tentative answers or hypotheses based on the question they have created. Next, students are asked to identify the variables that influence the problem provided. Then, students are asked to formulate a hypothesis regarding the experiment to be conducted related to the relationship between variables. In the basic support aspect, the pretest and posttest results yielded an N-Gain value of 0.59, which is categorized as Medium. The aspect measured in the basic support question is found in item number 4. Below is a snippet of the question presented in Figure 5.

4. Evi sedang melakukan percobaan gelombang tali *menggunakan PhET (Physics Education Technology)*. Gambar berikut adalah salah satu data yang diamati oleh Evi



Evi menulis besaran fisis gelombang berdasarkan gambar adalah sebagai berikut.

a) Amplitudo gelombang adalah 0,8 cm
b) Banyaknya gelombang yang terbentuk pada tali yaitu 3 gelombang
c) Frekuensi gelombang adalah 1,5 Hz
d) Panjang gelombangnya adalah 10cm
e) Periode gelombang yaitu 0,67 s
f) Cepat rambat gelombangnya 0,063 m/s

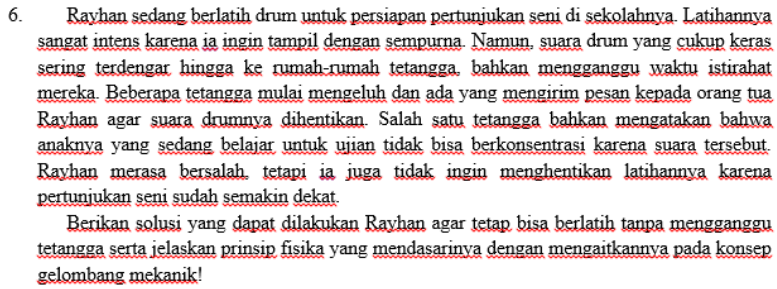
Bantulah Evi untuk mengidentifikasi apakah besaran fisis yang ia tulis sudah benar. Identifikasilah setiap pernyataan Evi apakah benar atau salah! Tulis jawaban yang tepat jika

Figure 5. Excerpt of question number 4.

Figure 5 shows an event where students are provided with stimuli in the form of experimental data on wave behavior and images from the PhET wave simulation. Students are required to examine each physical quantity listed by Evi, identify whether it is correct or incorrect, and provide an explanation

using calculations or principles underlying wave behavior to confirm the accuracy of the observations. During the pretest, some students faced difficulties in answering the question due to a lack of knowledge about explaining using calculations or the principles that underpin wave phenomena. However, during the posttest, some students demonstrated improved abilities to provide explanations using calculations or principles underlying waves after the implementation of the REACT strategy with PhET Simulation.

Figure 6 presents a question where students are asked to provide advanced clarification and support their arguments with evidence. In this aspect, students analyze observation data and summarize the results from the data they have obtained in collaboration with their group members. The results from the pretest and posttest for this aspect show an N-Gain score of 0.45, categorized as medium. The aspect measured in the question is listed as number 6. Below is an excerpt from the question presented in Figure 6.



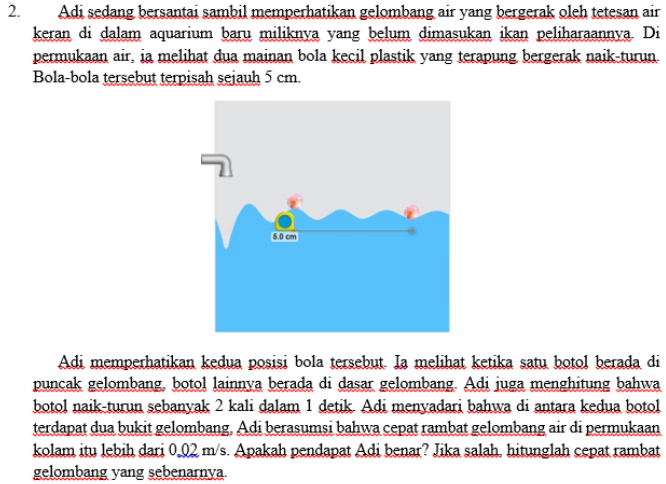
6. Rayhan sedang berlatih drum untuk persiapan pertunjukan seni di sekolahnya. Latihannya sangat intens karena ia ingin tampil dengan sempurna. Namun, suara drum yang cukup keras sering terdengar hingga ke rumah-rumah tetangga, bahkan mengganggu waktu istirahat mereka. Beberapa tetangga mulai mengeluh dan ada yang mengirim pesan kepada orang tua Rayhan agar suara drumnya dihentikan. Salah satu tetangga bahkan mengatakan bahwa anaknya yang sedang belajar untuk ujian tidak bisa berkonsentrasi karena suara tersebut. Rayhan merasa bersalah, tetapi ia juga tidak ingin menghentikan latihannya karena pertunjukan seni sudah semakin dekat.

Berikan solusi yang dapat dilakukan Rayhan agar tetap bisa berlatih tanpa mengganggu tetangga serta jelaskan prinsip fisika yang mendasarinya dengan mengaitkannya pada konsep gelombang mekanik!

Figure 6. Excerpt of question number 6.

Figure 6 shows a scenario where students are provided with a stimulus in the form of a text about Rayhan, who practices the drums loudly, disturbing the neighbors. Students are asked to formulate a solution so that Rayhan can continue practicing without disturbing the neighbors and explain the underlying physics principle of the solution, relating it to the concept of mechanical waves. During the pretest, some students had difficulty answering the question due to a lack of knowledge in providing advanced explanations using calculations or principles related to waves. However, after the posttest, several students began to demonstrate the ability to provide advanced explanations using wave principles after the REACT strategy, supported by PhET Simulation, was applied.

In the aspect of concluding (inference), students are able to draw conclusions from the experimental results obtained through virtual practicum activities. Students engage in group discussions to answer the given problems and determine conclusions from the experiments they have conducted. In the aspect of concluding, the pretest and posttest results yield an N-Gain score of 0.50, categorized as medium. The aspect measured in this question is item number 2. Here is the excerpt of the question shown in Figure 7.



2. Adi sedang bersantai sambil memperhatikan gelombang air yang bergerak oleh tetesan air keran di dalam aquarium baru miliknya yang belum dimasukan ikan peliharaannya. Di permukaan air, ia melihat dua mainan bola kecil plastik yang terapung bergerak naik-turun. Bola-bola tersebut terpisah sejauh 5 cm.

Adi memperhatikan kedua posisi bola tersebut. Ia melihat ketika satu botol berada di puncak gelombang, botol lainnya berada di dasar gelombang. Adi juga menghitung bahwa botol naik-turun sebanyak 2 kali dalam 1 detik. Adi menyadari bahwa di antara kedua botol terdapat dua bukit gelombang, Adi berasumsi bahwa cepat rambat gelombang air di permukaan kolam itu lebih dari 0,02 m/s. Apakah pendapat Adi benar? Jika salah, hitunglah cepat rambat gelombang yang sebenarnya.

Figure 7. Excerpt of question number 2.

Figure 7 illustrates a scenario in which students are given a stimulus in the form of a description of Adi's behavior, who is observing two floating balls on the water surface moving up and down, along with an illustration. Students are expected to identify Adi's assumptions regarding the wave speed and use this information to answer the problem and draw conclusions about the actual wave speed calculation. During the pretest, some students faced difficulties in answering the question, likely due to a lack of knowledge about calculating the actual wave speed. However, after the posttest, some students demonstrated an improved ability to conclude using mechanical wave principles, following the application of the REACT strategy supported by PhET Simulation.

In the aspect of strategy and tactics, students are required to formulate strategies and tactics to apply concepts in cases or problems. In this aspect, the results of the pretest and posttest yield an N-Gain score of 0.83, which falls into the High category. The aspect measured in the question is found in item number 7. Below is a snippet of the question presented in Figure 8.


7. Sebuah kapal penjelajah sedang berlayar di lautan dan perlu memastikan bahwa jalur yang akan dilalui aman dari rintangan bawah laut seperti karang atau kapal selam yang tidak terdeteksi oleh radar biasa. Kapten kapal ingin mengetahui apakah ada objek di bawah permukaan air tanpa harus mengirim penyelam, karena kondisi laut dalam yang berbahaya dan visibilitas yang rendah.

Untuk mengatasi masalah ini, para insinyur di kapal menggunakan suatu teknologi yang dapat mendeteksi objek di bawah air dengan cara mengirimkan gelombang tertentu, lalu menganalisis pantulannya. Dengan teknologi, mereka dapat mengukur kedalaman laut dan mengetahui keberadaan benda di bawah kapal. Alat apa yang kemungkinan digunakan oleh kapal untuk mendeteksi objek di bawah laut? Jelaskan prinsip kerja alat tersebut!

Figure 8. Excerpt of question number 7.

Figure 8 illustrates a scenario where students are given a stimulus in the form of a description of a ship using technology to detect objects and enemies at sea, along with an image. Students are asked to explain how a submarine can move without hitting objects by using the reflection of ultrasonic waves. During the pretest, some students had difficulty answering the question due to a lack of knowledge about the sound navigation and ranging (SONAR) technology used by ships. However, after the posttest, several students demonstrated the ability to explain the working principle of SONAR using the concept of mechanical waves after the REACT strategy was implemented with the aid of PhET Simulation.

To measure the effect of the REACT strategy aided by PhET Simulation on enhancing students' critical thinking skills, the effect size can be calculated using Cohen's d formula. Below is the summary of the data from the effect size calculations presented in Table 3.

Table 3. Recapitulation of critical thinking effect size.

	Average	Standard Deviation	D Value	Category
Pretest	21.94	10.47	3.19	High
Posttest	65.60	16.25		

Based on Table 3, it is found that the effect size value is 3.19, which falls into the high category. This indicates that the implementation of the REACT strategy aided by PhET Simulation has a strong impact on improving students' critical thinking skills.

4. Conclusion

The results of the study indicate that the implementation of the REACT strategy aided by PhET Simulation enhances students' critical thinking skills in the medium category. Its effectiveness is

considered high. The majority of students responded positively, agreeing or strongly agreeing with this strategy.

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