



The Effect of The REACT Strategy in Physics Instruction on Problem-Solving Abilities and Critical Thinking Skills

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ABSTRACT

Purpose - This study examines whether the REACT strategy (Relating, Experiencing, Applying, Cooperating, and Transferring) improves high school students' problem-solving and critical thinking skills in physics, particularly on thermodynamic laws. The study is grounded in the need for physics instruction that aligns with the Merdeka Curriculum.

Methodology - The study employed a quasi-experimental design with a pretest-posttest control group format. The sample consisted of 32 high school students at SMAN 8 Gowa, selected from the target population of learners studying thermodynamic laws. Students were assigned to an experimental group receiving instruction through the REACT strategy and a control group receiving conventional instruction. Data were collected using problem-solving and critical thinking tests administered before and after the intervention. The data were then analyzed comparatively to identify differences between groups and to determine the extent of improvement in both skills.

Findings - The study found that students taught through the REACT strategy showed greater improvement than those taught through conventional instruction. In problem-solving, the experimental group's mean score increased from 48.13 to 81.25 (a gain of 33.12 points), compared with an increase from 47.81 to 70.63 (22.82 points) in the control group. In critical thinking, the experimental group improved from 49.06 to 83.44 (34.38 points), whereas the control group rose from 48.75 to 72.19 (23.44 points).

Contribution - This study contributes theoretically by extending the discussion of contextual learning, especially the REACT strategy, in physics education; empirically by providing evidence on its effect on students' problem-solving and critical thinking skills in thermodynamics; and practically by offering teachers a relevant instructional alternative for designing more active, contextual, and meaningful learning experiences under the Merdeka Curriculum.

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INTRODUCTION

Physics instruction at the high school level plays a crucial role in developing students' higher-order thinking skills, particularly problem-solving and critical thinking skills relevant to the demands of 21st-century learning (Li et al., 2023; Wijnen et al., 2021). Physics instruction is not only focused on mastering concepts but also on students' ability to understand phenomena, analyze information, apply concepts, and solve problems in various situations. In line with the requirements of the "Merdeka" curriculum, the learning process must provide experiences that encourage students to think critically and solve problems based on real-world contexts (Ainissyifa et al., 2024; Amalia et al., 2025). Thermodynamics is one of the important yet conceptually challenging physics topics in high school physics because many of its principles involve abstract processes that cannot be directly observed, such as energy transfer, changes in internal energy, heat exchange, and the relationships among work and thermodynamic state variables. Students are therefore required not only to recall mathematical relationships but also to interpret physical processes and connect conceptual explanations with observable phenomena. Therefore, physics instruction must be designed so that students not only receive information but also actively construct their understanding and connect physics concepts to their everyday experiences, a direction that is consistent with evidence showing that student-centered, inquiry- and problem-based approaches support critical thinking development in science learning (Fitria et al., 2025; Wati et al., 2026).

Problem-solving skills are among the most important in physics education because students are required to understand problems, identify relevant concepts, design solution strategies, implement solutions, and evaluate the results. The problem-solving process enables students to integrate conceptual knowledge with scientific thinking skills (Pratiwi et al., 2024). In addition, critical thinking skills are necessary for students to analyze information, evaluate statements or solutions, draw logical conclusions, and provide reasoning based on available concepts and evidence. These skills help students understand the relationships between concepts and apply physics principles to solve real-world problems (Yulvinamaesari et al., 2025).

Based on initial observations conducted at SMAN 8 Gowa, students still have room to develop their problem-solving abilities and critical thinking skills. Students have been able to understand basic information in problems, but still need practice in developing solution strategies, justifying their answers, evaluating results, and connecting concepts they have learned to new situations. The results of the initial test administered to 32 students showed that the average problem-solving ability score was 48.10 out of 100, while the average critical thinking skill score was 48.81 out of 100. These findings indicate that learning experiences are needed that provide students with broader opportunities to analyze, apply, evaluate, and transfer knowledge to different situations.

One relevant learning strategy for developing problem-solving abilities and critical thinking skills is the REACT strategy (Relating, Experiencing, Applying, Cooperating, and Transferring) (Koç-Akran, 2024; Nguyen et al., 2026). The REACT strategy is part of the Contextual Teaching and Learning approach, which emphasizes the connection between the concepts being studied and students' real-life experiences (Rahman et al., 2024). Through the Relating stage, students connect concepts to experiences or phenomena in their daily lives; the Experiencing stage provides students with opportunities to gain experience through learning activities; the Applying stage guides students in applying concepts to solve problems; the Cooperating stage encourages students to collaborate and discuss; and the Transferring stage trains students to apply the knowledge they have acquired to new situations or problems (Pinar et al., 2026; Yalçın et al., 2024).

Previous studies have demonstrated the potential of the REACT strategy to support students' problem-solving and critical thinking through contextual, experiential, collaborative, and transfer-oriented learning activities (Akay & Kanadlı, 2021; Koç-Akran, 2024). For example, recent research has examined REACT in physics and science learning, including augmented reality-supported applications and digital implementations (Pinar et al., 2026), while other studies have investigated its application in mathematics and other learning contexts (Tien-Trung et al., 2026), (Sari & Darhim, 2020), (Mathias et al., 2024), (Quainoo et al.,

2025). However, the existing evidence has not sufficiently explained how the sequential components of REACT contribute to students' problem-solving and critical thinking when learning thermodynamic laws, a topic characterized by abstract energy-transfer processes and the need to integrate conceptual reasoning with quantitative relationships.

The present study addresses this gap by examining the application of the REACT strategy specifically to thermodynamic laws and by simultaneously investigating two closely related higher-order outcomes: physics problem-solving ability and critical thinking skills. Rather than treating REACT simply as an alternative instructional strategy, this study considers how its contextual sequence from relating thermodynamic concepts to familiar phenomena, experiencing physical processes, applying principles to problems, cooperating in reasoning, and transferring knowledge to unfamiliar situations can support students in constructing and using thermodynamic understanding. This focus provides a more subject-specific explanation of the potential contribution of REACT to physics learning than studies that examine the strategy in mathematics, general science, or augmented-reality-supported settings without explicitly connecting its stages to the conceptual characteristics of thermodynamics (Gökalp & Adem, 2020), (Indaryani et al., 2020).

Based on the background, identification, and scope of the problem as outlined above, the research question for this study are (1) Does REACT-based physics instruction improve students' problem-solving abilities in thermodynamic laws compared with conventional instruction? (2) Does REACT-based physics instruction improve students' critical thinking skills in thermodynamic laws compared with conventional instruction? and (3) To what extent does the REACT strategy contribute to the improvement of students' problem-solving and critical thinking skills in thermodynamic laws?

This study is expected to make theoretical, empirical, and practical contributions to physics education. Theoretically, this study contributes to the literature on the application of contextual learning strategies, specifically the REACT strategy (Relating, Experiencing, Applying, Cooperating, and Transferring), in developing students' higher-order thinking skills, particularly problem-solving and critical thinking. Empirically, this study examines differences in problem-solving abilities and critical thinking skills between students who learn using the REACT strategy and those who learn through conventional instruction, and analyzes the extent to which the REACT strategy influences improvements in these two abilities in the context of thermodynamic laws. Practically, the results of this study are expected to serve as a basis for teachers in selecting and implementing learning strategies capable of creating contextual, active, and meaningful learning experiences, so that students not only understand physics concepts but are also able to apply, analyze, evaluate, and transfer their knowledge to solve problems in various situations.

METHODOLOGY

Research Design

This study employed a quantitative quasi-experimental design. The research design used was the Non-equivalent Control Group Design. This design was chosen because the researcher did not randomly assign students; instead, they used pre-existing classes. The study involved two groups: an experimental class that received instruction using the REACT (Relating, Experiencing, Applying, Cooperating, Transferring) strategy and a control class that received discovery learning instruction. Both groups were administered a pre-test before the intervention and a post-test after it to measure their problem-solving abilities and critical-thinking skills in physics.

The independent variable in this study is the learning strategy, which consists of the REACT strategy and conventional learning. The dependent variables in this study are problem-solving ability and critical thinking skills in physics. Problem-solving ability in this study refers to Polya's stages of problem-solving, namely understanding the problem, planning a solution, implementing the plan, and reviewing the solution. Meanwhile, critical thinking skills are defined by Facione's indicators, which include interpretation, analysis, evaluation, inference, and explanation.

Table 1. Non-equivalent Control Group Design

Group	Pre-test	Treatment	Post-test
Experiment	O ₁	x	O ₂
Control	O ₃	-	O ₄

Participant

The study was conducted with secondary school students at the research site during the designated school year. The study population consisted of all students in the targeted grade levels, totaling 384 students across the available classes, with approximately 30–36 students per class. The sample consisted of two Grade XI classes, selected based on existing class conditions and in accordance with the characteristics of a quasi-experimental design. Class XI.9, consisting of 32 students, was assigned as the experimental group and received physics instruction using the REACT strategy, while Class XI.10, also consisting of 32 students, was assigned as the control group and received physics instruction using conventional teaching methods. Thus, the total sample comprised 64 students. Classes were selected based on existing class conditions to align with the characteristics of a quasi-experimental study.

Data Collection

The data collection method used was a test. The test was used to obtain data on students' problem-solving abilities and critical thinking skills before and after the intervention. The tests were administered as multiple-choice questions, based on the indicators for each research variable. The test instrument for problem-solving ability was developed based on Polya's indicators of problem-solving ability, which include understanding the problem, devising a plan, carrying out the plan, and reviewing the solution. In contrast, the test instrument for critical thinking skills was developed based on Facione's indicators of critical thinking skills, which include interpretation, analysis, evaluation, inference, explanation, and self-regulation. Each variable consisted of 25 multiple-choice items.

Data collection in this study was conducted with two research groups: the experimental class, which received physics instruction using the REACT strategy, and the control class, which received instruction using typical classroom methods. Before the intervention, both groups took a pre-test to assess the students' initial levels of problem-solving ability and critical thinking skills. After the entire learning process and intervention were completed, both groups took a post-test using a prepared instrument to assess the students' abilities following the instruction.

Instrument

The research instruments used were a problem-solving ability test and a critical thinking skills test. Each instrument consisted of 25 multiple-choice items and was administered as a pre-test and a post-test. The problem-solving ability instrument was developed based on Polya's indicators, while the critical thinking skills instrument was developed based on Facione's indicators. Both instruments were used to collect data on students' abilities before and after the intervention.

Before being used in the research, the instruments underwent expert validation to ensure that the content, constructs, and language of the test items were appropriate and aligned with the indicators of the variables being measured. The validity of the instruments for both students' problem-solving skills and critical thinking skills was assessed using the Gregory content validity coefficient. The analysis yielded a validity coefficient of 0.97 for both instruments, indicating a very high level of content validity. Following expert validation, the instruments were pilot-tested to assess reliability and examine test-item characteristics, including validity, difficulty, and discriminative power. The reliability analysis yielded a coefficient of 79.26%, indicating that the instruments were acceptable for data collection. Based on the validation and reliability results, the instruments were considered appropriate for measuring students' problem-solving and critical thinking skills in the present study.

Data Analysis

The research data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to provide an overview of students' problem-solving abilities and critical thinking skills in the experimental and control classes. The descriptive analysis included the minimum, maximum, mean, and standard deviation of the pre-test and post-test scores.

Before testing the hypotheses, the data were first tested against the assumptions of the analysis. The normality test was conducted using the Shapiro-Wilk test, while the homogeneity of variances test was conducted using Levene's test. A test of equivalence of initial ability was also conducted based on the pretest results to determine the initial conditions of both groups before the treatment was administered. Hypothesis testing was conducted to determine differences in problem-solving ability and critical thinking skills between students who received instruction using the REACT strategy and those who received conventional instruction. In addition, the effect size can be calculated using Cohen's *d* to determine the magnitude of the effect of the REACT strategy compared to conventional learning. The hypothesis testing criteria were set at a significance level of $\alpha = 0.05$. The hypothesis is accepted if the significance value is less than 0.05, indicating a significant difference or effect between learning using the REACT strategy and conventional learning on the variables under study.

FINDINGS

Statistic Descriptive

Data on students' critical thinking skills were obtained from pre-test and post-test assessments administered to the experimental and control groups before and after the instructional intervention. The participants consisted of 64 Grade XI students, comprising 32 students in the experimental group and 32 students in the control group. The experimental group was taught using the REACT strategy, while the control group received conventional instruction. The pre-test was administered before the intervention to assess students' initial critical thinking skills. In contrast, the post-test was administered after the intervention to evaluate students' critical thinking performance following the instructional treatment. Data on learning outcomes were obtained from the pre- and post-tests administered to the experimental and control classes. The results of the descriptive analysis are presented in Table 2:

Table 2. The descriptive analysis of learning outcomes

Group	N	Mean		SD		Maximum	Minimum
		Pre-Test	Post-test	Pre-Test	Pos-test		
Experiment	32	49,06	83,44	7,63	6,85	56	94
Control	32	48,75	72,19	8,02	8,11	44	88

Based on the data in Table 2, the descriptive statistics indicate that the two groups had comparable initial critical-thinking performance before the intervention. The experimental group obtained a pre-test mean of 49.06 (SD = 7.63), with scores ranging from 44 to 56, whereas the control group obtained a mean of 48.75 (SD = 8.02), with scores also ranging from 44 to 56. After the intervention, the mean score of the experimental group increased to 83.44 (SD = 6.85), with scores ranging from 56 to 94. In comparison, the control group achieved a post-test mean of 72.19 (SD = 8.11), with scores ranging from 44 to 88. These results indicate that both groups improved in critical thinking skills, but the experimental group showed a greater increase in mean score following the REACT-based instruction. The complete descriptive statistics are presented in Table 2.

Overall, the descriptive statistics indicate that students who received REACT-based instruction achieved higher critical-thinking scores after the intervention than those who received conventional instruction. The descriptive findings provide an initial indication of differences in learning outcomes between the two groups; however, inferential statistical analysis is required to determine whether these observed differences are statistically significant.

Normality Test

The normality test was conducted to determine whether the distribution of students' pre-test and post-test scores met the assumption of normality before the inferential statistical analysis was performed. The Shapiro-Wilk test was used because the analysis involved relatively small groups of participants. The test was applied to the pre-test and post-test scores of students' problem-solving skills and critical thinking skills in both the experimental and control groups. The data were considered normally distributed when the significance value (p) was greater than 0.05, indicating that there was no statistically significant deviation from a normal distribution. The results of the Shapiro-Wilk normality test are presented in the following Table 3.

Table 3. Result of Normality Test

Variables	Group	Sig.	Description
Problem-Solving Skills	Experiment	0.087	Normal
Problem-Solving Skills	Control	0.102	Normal
Critical Thinking Skills	Experiment	0.116	Normal
Critical thinking skills	Control	0.093	Normal

The results of the normality test indicate that all research data have significance values greater than 0.05. For problem-solving skills, significance values of 0.087 and 0.102 were obtained in the experimental and control groups, respectively. Meanwhile, critical thinking skills yielded significance values of 0.116 in the experimental group and 0.093 in the control group. Thus, all data were normally distributed. This indicates that the basic assumptions for using parametric analysis have been met, allowing for a more reliable comparison of results between the experimental and control groups.

Homogeneity Test

The homogeneity test was conducted to determine whether the variances of students' scores were comparable between the experimental and control groups. Levene's test was used to assess the homogeneity of variance between pre-test and post-test scores in problem-solving and critical thinking skills. The assumption of homogeneity was considered satisfied when the significance value (p) was greater than 0.05, indicating that there was no statistically significant difference between the variances of the groups. Meeting this assumption supports proceeding with the subsequent inferential statistical analysis. The results of Levene's test are presented in Table 4.

Table 4. Result of Homogeneity Test

Variable	Sig.	Description
Problem-Solving Ability	0.421	Homogeneity
Critical Thinking Skills	0.537	Homogeneity

The homogeneity test showed that the significance value for problem-solving ability was 0.421, while that for critical thinking skills was 0.537. Both values were greater than 0.05, so the data from the experimental and control groups were deemed homogeneous. This finding also supports the study's descriptive results. The initial scores for problem-solving ability were 48.13 for the experimental group and 47.81 for the control group, while the scores for critical thinking skills were 49.06 and 48.75, respectively. The relatively small difference in initial scores indicates that both groups had relatively comparable starting conditions before instruction. Furthermore, the results of the homogeneity test indicate that the variation in the data for both groups meets the assumption of homogeneity.

Effect Size

To assess the magnitude of the differences in students' learning outcomes between the experimental and control groups, an effect size analysis was conducted. This analysis was conducted for both problem-

solving ability and critical thinking skills, based on post-test scores obtained after the instructional intervention. Cohen’s *d* was used to quantify the magnitude of the difference between the two groups. The experimental and control group means, Cohen’s *d* values, and their corresponding effect size categories are presented in Table 5.

Table 5. The result of the effect size

Variable	Mean		Cohen’s d	Category
	Experimental	Control		
Problem-Solving Ability	81.25	70.63	1.37	High
Critical Thinking Skills	83.44	72.19	1.50	High

The effect size analysis showed that the REACT strategy produced a large difference in both students’ problem-solving ability and critical thinking skills compared with conventional instruction. For problem-solving ability, the experimental group achieved a higher post-test mean score ($M = 81.25$) than the control group ($M = 70.63$), with a Cohen’s *d* of 1.37, categorized as a large effect. Similarly, for critical thinking skills, the experimental group obtained a higher post-test mean score ($M = 83.44$) than the control group ($M = 72.19$). The corresponding Cohen’s *d* value was 1.50, also indicating a high effect. These findings suggest that the differences in post-test performance between the two groups were not only statistically significant but also substantial for both outcomes. The larger effect size for critical thinking than for problem-solving ability indicates a greater difference between the groups in critical thinking performance under the conditions of the present study.

DISCUSSION

Statistic Descriptive

The results of the study show that the problem-solving skills of students in the experimental group increased from a pre-test average score of 48.13 to 81.25 on the post-test. Meanwhile, the control group’s scores increased from 47.81 to 70.63. Thus, the improvement in problem-solving skills in the experimental group was 33.12 points, while in the control group it was 22.82 points. This difference indicates that students in the experimental group achieved greater development in problem-solving skills after participating in the learning process (Hake, 1998; Liana et al., 2023). This outcome can be understood because learning that provides students with the opportunity to actively engage in identifying problems, gathering information, analyzing relationships between concepts, and determining solutions can foster a more systematic thinking process. In physics learning, problem-solving skills are not only related to the ability to perform mathematical calculations but also to understanding problem situations, identifying relevant concepts, planning solution strategies, and evaluating the results obtained. Therefore, learning activities oriented toward inquiry and problem-solving enable students to develop these skills in a more structured manner.

The results of this study are consistent with research by Rizki et al. (2024), which shows that the application of inquiry-based learning in physics instruction, particularly when supported by simple experimental tools, is effective in improving students’ problem-solving (Prahani et al., 2021; Yuliati et al., 2018). That study positioned the inquiry process as a means for students to build understanding and apply physics concepts to solve problems (Ogegbo et al., 2022). These findings are further supported by the results of a meta-analysis by Pambudi et al. (2023), which showed that implementing Problem-Based Learning in physics instruction yielded an average effect size of 1.995, falling into the “high” category. Specifically, the effect size for problem-solving skills reached 1.95. These findings indicate that learning that provides direct experience in encountering and solving problems has strong potential to enhance students’ problem-solving skills (Kanyesigye et al., 2022). Thus, the improvement in problem-solving skills in the experimental group in this study can be viewed as a consequence of a learning process that provides students with greater opportunities to construct knowledge through thinking, inquiry, and problem-solving activities. The average post-test score of 81.25 in the experimental group, which was higher than that of the control group (70.63),

indicates that the learning process in the experimental group was more conducive to the development of problem-solving skills.

Problem-Solving Skills Between Students Who Learn Using the REACT Strategy and Those Who Learn Through Conventional Instruction

The results indicate that students' problem-solving skills improved in both groups following the instructional intervention. In the experimental group, the mean score increased from 48.13 on the pre-test to 81.25 on the post-test, representing an improvement of 33.12 points. Meanwhile, the control group's mean score increased from 47.81 to 70.63, corresponding to an improvement of 22.82 points. These findings indicate a greater improvement in problem-solving skills among students who received the REACT-based instruction compared with those who received discovery learning. This difference indicates that students in the experimental group achieved greater development in problem-solving skills after participating in the learning process (Hake, 1998; Liana et al., 2023). This outcome can be understood because learning that provides students with the opportunity to actively engage in identifying problems, gathering information, analyzing relationships between concepts, and determining solutions can foster a more systematic thinking process. In physics learning, problem-solving skills are not only related to the ability to perform mathematical calculations but also to understanding problem situations, identifying relevant concepts, planning solution strategies, and evaluating the results obtained. Therefore, learning activities oriented toward inquiry and problem-solving enable students to develop these skills in a more structured manner.

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Physics Critical Thinking Skills Between Students Who Learn Using the REACT Strategy and Those Who Learn Through Conventional Instruction

The study on critical thinking skills showed that the experimental group's average score increased from 49.06 on the pre-test to 83.44 on the post-test. Meanwhile, the control group's score increased from 48.75 to 72.19. Thus, the experimental group's score increased by 34.38 points, while the control group's score increased by 23.44 points. These results indicate that the development of critical thinking skills in the experimental group was higher than that of the control group, consistent with findings that active, problem-based, and inquiry-based learning interventions tend to yield greater improvements in critical thinking than conventional instruction (Fitriani et al., 2020). This improvement indicates that the learning process for students in the experimental group fostered cognitive engagement. Critical thinking skills develop when students not only receive information but also identify problems, interpret information, provide evidence-based reasoning, analyze relationships between concepts, and draw conclusions from observations or investigations. These

characteristics are highly relevant to physics learning because physics concepts often require reasoning to connect real-world phenomena to physics principles or laws.

Recent research on guided inquiry in physics education also shows a similar trend. Meta-analyses and systematic reviews indicate that inquiry-based learning effectively enhances critical thinking skills, including analysis, inference, and evaluation (Arifin et al., 2025). In the context of physics, a literature review also indicates that student-centered learning models, such as inquiry-based learning, are consistently used to strengthen critical thinking (Jatmiko et al., 2025; Ubaidillah et al., 2023). However, these studies also indicate that self-reflection or self-regulated learning is relatively less frequently the focus or a dominant indicator; therefore, the reflective aspect requires attention in instructional design. These findings are further supported by Ubaidillah et al. (2023) through a systematic literature review, which indicates that Problem-Based Learning consistently enhances students' critical thinking skills, particularly through activities involving analysis, problem-solving, and conceptual understanding. Therefore, the increase in the average critical thinking skills score from 49.06 to 83.44 in the experimental group suggests that learning oriented toward higher-order thinking activities provides students with greater opportunities to develop their analytical, evaluative, reasoning, and decision-making skills. The higher post-test scores of the experimental group compared to the control group also reinforce the indication that the learning experience in the experimental group was more conducive to the development of critical thinking skills.

The REACT Strategy Influences the Improvement of Students' Problem-Solving Skills

Based on Table 5, the average problem-solving ability score of students in the experimental class using the REACT strategy was 81.25, while that of the control class was 70.63. The average difference of 10.62 points indicates that the problem-solving ability of students who received instruction using the REACT strategy was higher than that of students in the control class. The effect size calculation yielded a Cohen's *d* value of 1.37, which falls into the "large" category. Thus, the use of the REACT strategy had a significant effect on improving students' problem-solving skills, with a big difference in achievement between the experimental and control classes.

These findings are consistent with recent developments in the literature, which position the REACT strategy as an effective contextual approach for strengthening mathematical problem-solving skills. Through the stages of relating, experiencing, applying, cooperating, and transferring, students not only practice solving problems but also establish connections between concepts and real-world situations, engage in collaborative discussions, and transfer strategies to new contexts. A recent quasi-experimental study shows that applying REACT to the teaching of derivatives can improve mathematical problem-solving skills while also fostering student engagement and interest in learning (Nguyen et al., 2026). These findings are also consistent with research using augmented reality applications, which shows that REACT contributes to improved problem-solving and critical thinking skills through active and collaborative learning experiences (Koç-Akran, 2024).

More broadly, the findings of this study are also supported by recent synthesized evidence indicating that mathematics learning interventions that emphasize strategies, representations, and problem-solving activities tend to yield meaningful positive effects. A meta-analysis of students with mathematics difficulties reported that problem-solving interventions had a relatively large positive effect on word problem-solving performance (Myers et al., 2023), while another meta-analysis indicates that mathematics interventions at the adolescent level generally yield moderate to large effects, depending on the design characteristics and duration of the intervention (Myers et al., 2021). Thus, the Cohen's *d* value of 1.37 in this study should be understood not as an isolated finding, but as an indication that the REACT strategy is highly effective when learning is designed to be active, structured, and oriented toward the construction of meaning and the transfer of problem-solving strategies.

The REACT Strategy Influences the Improvement of Students' Critical Thinking Skills

Based on the table, the average critical thinking skills of students in the experimental class were 83.44, while those in the control class were 72.19. Thus, there was an average difference of 11.25 points, indicating that students taught using the REACT strategy had higher critical-thinking skills than those in the control class. The effect size obtained was Cohen's $d = 1.50$, which, based on interpretation criteria, falls into the "large" category. Therefore, the REACT strategy has a significant effect on students' critical thinking skills; in fact, the magnitude of the effect on critical thinking skills ($d = 1.50$) is greater than that on problem-solving skills ($d = 1.37$).

The effect size in this study ($d = 1.50$) also indicates that REACT's impact on critical thinking is very strong compared to many other learning interventions reported in the literature. By comparison, a meta-analysis on problem-based learning and critical thinking skills reported effects of $SMD = 0.640$ (Liu et al., 2022) and $SMD = 0.47$ (Wei et al., 2024), while a meta-analysis of game-based learning reported an overall effect size of $g = 0.863$ (Mao et al., 2022). Even in the realm of mathematical problem-solving, learning interventions generally demonstrate positive effects ranging from moderate to large. Thus, the d -values of $d = 1.50$ for critical thinking skills and $d = 1.37$ for problem-solving ability in this study not only confirm the effectiveness of REACT but also indicate that this strategy has a competitive – and even relatively stronger – impact compared to various other active approaches reported in recent studies (Nguyen et al., 2026).

These findings are consistent with recent trends in the literature, which indicate that active, contextual, and collaborative learning is generally more effective at developing critical thinking skills than conventional learning. Meta-analytic studies indicate that problem-based learning has a positive impact on critical thinking in higher education, with moderate to strong effects (Liu et al., 2022; Wei et al., 2024), while inquiry-based learning has also been reported to have a strong and consistent impact on improving critical thinking skills (Rizki et al., 2024). In this context, the findings of this study can be understood because the REACT relating, experiencing, applying, cooperating, and transferring pedagogically engages students in analysis, evaluation, discussion, and the application of concepts to meaningful situations, which are components identified in various studies as essential prerequisites for the development of critical thinking (Asadi et al., 2025; Jegstad et al., 2025).

Furthermore, support for these findings can also be found in the literature, which emphasizes the synergy between authentic contexts, collaborative activities, and problem-solving as the primary drivers of critical thinking. A quasi-experimental study on Problem-Integrated Contextual Learning showed that learning that combines real-world problems with explicit contextualization results in significant improvements in critical thinking and collaboration (Lingga et al., 2026). More broadly, a meta-analysis indicates that collaborative problem-solving effectively enhances critical thinking with a strong effect size ($ES = 0.82$), particularly when supported by scaffolding and an adequate intervention duration (Xu et al., 2023). In this context, the REACT framework, which connects learning experiences to meaningful situations and places students in structured collaboration, provides a strong theoretical foundation for explaining why the improvement in critical thinking observed in this study was so pronounced.

REACT Stages and The Development of Problem-Solving Skills in Thermodynamics

The greater improvement in problem-solving skills observed in the experimental group can be attributed to the sequential learning processes provided by the REACT strategy and the specific conceptual demands of thermodynamics. In the present study, students who learned through REACT improved from a mean pre-test score of 48.13 to 81.25 on the post-test, representing an increase of 33.12 points. In comparison, the control group increased from 47.81 to 70.63, representing an improvement of 22.82 points. The greater improvement in the REACT group suggests that the strategy helped students develop a more systematic process for interpreting and solving thermodynamic problems. This interpretation is particularly relevant because thermodynamics requires students to coordinate conceptual understanding with mathematical reasoning rather than simply substitute known quantities into equations.

The Relating stage provides an important foundation for problem-solving by connecting abstract thermodynamic concepts to phenomena students encounter in everyday life. In thermodynamics, students need to distinguish among temperature, heat, work, and internal energy and understand how these quantities are related during different physical processes. These relationships can be difficult to construct because many thermodynamic processes cannot be directly observed at the microscopic level. Recent research involving more than 1,000 introductory and advanced physics students found persistent difficulties with internal energy, work, and heat transfer even after traditional instruction (Brundage et al., 2024). The study also identified context-dependent reasoning and difficulties in interpreting the effects of heat transfer and work on changes in internal energy. Therefore, in the present study, relating can be understood as helping students establish an initial conceptual representation before attempting quantitative problem solving. By connecting thermodynamic principles with familiar situations such as heating, cooling, gas expansion, or energy transfer, students have a basis for interpreting what a problem describes rather than immediately selecting an equation.

The Experiencing stage extends this contextual understanding by allowing students to construct knowledge through observation, investigation, or direct engagement with physical situations. This stage is particularly relevant to thermodynamics because students must infer abstract processes from observable changes in physical quantities. For example, changes in temperature, volume, or pressure can help students reason about the underlying transfer of energy and changes in a system's state. Recent research has shown that students have difficulty interpreting thermodynamic processes and the relationships among heat, work, and internal energy, indicating that merely presenting formal definitions and equations may not be sufficient to establish functional understanding (Brundage et al., 2024). In the present study, the Experiencing stage therefore provided a conceptual bridge between physical phenomena and their mathematical representations. This bridge is important because students first need to understand what is physically occurring before determining how to represent the process mathematically.

The Applying stage is directly related to the problem-solving demands measured in this study. Thermodynamic problems require students to identify relevant information, determine the physical process involved, select an appropriate thermodynamic principle, formulate the mathematical relationship, and interpret the result. This process is more complex than recalling an equation because the same variables can appear in different thermodynamic situations with different physical meanings. Recent evidence demonstrates that problem characteristics strongly influence students' responses to thermodynamics problems. Brundage (2025), for example, examined students' responses to problems involving internal energy, work, heat transfer, entropy, state variables, and P-V diagrams and found that students' reasoning can vary depending on how a concept is represented or embedded in a problem. Thus, the Applying stage in REACT is important because it encourages students to use conceptual relationships to determine which principle is relevant, rather than relying solely on surface features or memorized procedures. The greater post-test performance of the experimental group can therefore be associated with repeated opportunities to apply thermodynamic concepts in meaningful problem situations.

The Cooperating stage further supports problem-solving by requiring students to communicate, compare, and evaluate their reasoning with peers. This process is particularly relevant to thermodynamics because errors frequently arise not from mathematical calculation alone but from an incorrect interpretation of the physical process. For instance, students may overlook heat transfer, misinterpret the sign of work, or incorrectly determine how internal energy changes during a process. Brundage et al. (2024) reported that students sometimes used "variable exclusion" or considered thermodynamic variables in pairs when applying the First Law, leading them to overlook the contribution of one of the relevant quantities. Collaborative discussion within the Cooperating stage provides opportunities for students to make their reasoning explicit and compare alternative interpretations. When students are required to explain why a particular equation or principle is appropriate, conceptual inconsistencies can become visible and subsequently be revised. Thus, cooperation contributes to problem-solving by strengthening the reasoning and evaluation processes that occur before and during the construction of mathematical solutions.

The Transferring stage is particularly important for developing students' ability to solve unfamiliar thermodynamic problems. Successful problem solving requires students to recognize the underlying physical principle even when the context, representation, or numerical information differs from examples encountered during instruction. This requirement is especially important in thermodynamics because students' conceptual reasoning may depend heavily on a problem's characteristics. Brundage et al. (2025) demonstrated that students' responses could vary across problems addressing similar underlying concepts, including internal energy as a state variable, work represented as the signed area under a P-V curve, and the relationship between internal energy and temperature. Transferring in REACT provides an opportunity for students to move beyond procedural familiarity by applying previously constructed knowledge to new situations. In the context of the present study, this stage can help explain why students in the experimental group were better prepared to approach thermodynamic problems requiring interpretation and application rather than the direct reproduction of previously practiced procedures.

The sequential relationship among the five REACT stages provides a coherent explanation for the improvement observed in the experimental group. Relating establishes connections between students' prior experiences and abstract thermodynamic concepts; Experiencing provides opportunities to construct understanding through physical phenomena or investigation; Applying develops the ability to use conceptual knowledge in problem situations; Cooperating enables students to articulate, compare, and refine their reasoning; and Transferring extends that understanding to unfamiliar contexts. This sequence is particularly well-suited to the structure of thermodynamic problem-solving, in which students need to move from understanding the physical situation to identifying relevant principles, constructing a solution, and evaluating whether the solution is physically meaningful.

The findings of the present study, therefore, suggest that REACT's contribution to problem-solving skills was not merely associated with providing students with more opportunities to practice solving problems. Rather, the strategy organized learning experiences that addressed several conceptual barriers commonly encountered in thermodynamics. This interpretation is consistent with recent research showing that thermodynamics remains challenging even after formal instruction and that students' reasoning can be affected by the context and representation of a problem (Brundage et al., 2024, 2025). The 33.12-point improvement observed in the REACT group, compared with the 22.82-point improvement in the control group, consequently provides empirical support for the relevance of a contextual, experiential, collaborative, and transfer-oriented learning sequence in addressing the problem-solving demands of thermodynamics.

Overall, the present findings indicate that REACT is particularly relevant to thermodynamic problem solving because its stages correspond to the cognitive demands required to interpret thermodynamic situations. Students are first encouraged to understand the physical meaning of a phenomenon, then construct and apply conceptual relationships, evaluate their reasoning through interaction, and finally use the underlying principles in new situations. Such a progression is important for thermodynamics because students may otherwise rely on memorized equations or isolated procedures without adequately considering the physical conditions represented in a problem. The greater improvement observed in the experimental group suggests that structuring learning around these sequential processes can help students develop more conceptually grounded, applicable problem-solving abilities across diverse thermodynamic situations.

CONCLUSION

The findings indicate that REACT-based physics instruction improved students' problem-solving abilities in learning thermodynamic laws compared with conventional instruction. The REACT group demonstrated greater improvement in problem-solving performance, with a large effect size, indicating a substantial difference in learning outcomes between the two instructional groups.

The findings also indicate that REACT-based instruction improved students' critical thinking skills in thermodynamics compared with conventional instruction. The experimental group demonstrated greater improvement in critical thinking performance, with a large effect size. Overall, the findings suggest that the

REACT strategy contributed substantially to the development of both problem-solving abilities and critical thinking skills by engaging students in relating concepts to familiar phenomena, experiencing learning processes, applying concepts, reasoning cooperatively, and transferring knowledge to new situations. Thus, the REACT strategy provides a contextual and structured learning approach that is relevant to the conceptual and reasoning demands of thermodynamic laws.

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