



Exploring Critical Thinking Skills for Solving Energy Scarcity Problems: Integrating Renewable Energy Contexts in Sustainable Physics Learning

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Abstract: The global energy crisis of the 21st Century demands that education play a role in developing students' critical thinking skills regarding sustainability issues. Physics education has the strategic potential to integrate renewable energy into its curriculum. However, its implementation in schools still tends to focus on mastery of concepts rather than on the Development of higher-order thinking skills. This study aims to explore students' critical thinking abilities in solving energy scarcity problems through physics learning based on the context of renewable energy. The study used a descriptive, quantitative approach and a survey method with 33 grade XI students at SMA Negeri 7 Surabaya. The research instruments included an essay test based on Facione's six critical thinking indicators, interviews, and learning observations. The data were analyzed using descriptive statistics and the Miles and Huberman model. The results showed that the students' critical thinking skills ranged from low to very low across all indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation. Students tended to provide incomplete, unstructured answers with minimal data and context-based arguments. These findings indicate the need to develop contextual physics learning that is problem-solving-oriented and integrated with renewable energy issues to improve students' critical thinking skills in addressing the challenges of energy scarcity.

Keywords: Critical Thinking; Renewable Energy; Physics Learning; Sustainability; Energy Scarcity.

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Introduction

The challenges of the 21st Century, with rapid technological developments and a global energy crisis that also affects Indonesia, pose a significant challenge for the world of education, requiring that all stakeholders, including students, be aware of and concerned about the crisis (Siregar, 2024). The world is experiencing a surge in energy demand due to increasing urbanization, industrialization, population growth, and technological advances (Abdul et al., 2025). It has triggered various environmental impacts, including increased carbon emissions, global warming, and climate change (Tjiwidjaja & Salima, 2023). This situation highlights a significant gap between energy

demand and the Earth's ability to provide safe, environmentally friendly, and sustainable energy sources. This situation demands a transformation of the global energy system towards renewable energy sources that are more efficient, sustainable, and capable of meeting long-term needs. Without strategic efforts across various sectors of life, we will face greater risks, ranging from economic instability to difficult-to-reverse ecosystem damage.

At the national level, energy scarcity is a serious concern. As a developing country, Indonesia faces a significant dilemma: balancing energy needs with ecosystem sustainability (Yulida & Novindra, 2025). Although Indonesia has enormous potential for

developing renewable energy sources such as solar, wind, biomass, and geothermal, their utilization remains limited. Infrastructure limitations and funding constraints contribute to the low adoption rate of renewable energy. However, the lack of public understanding about the importance of energy transition also plays a role. In addition, the issue of sustainable energy is rarely integrated into education. Low public awareness, limited infrastructure, and financial problems can exacerbate the imbalance between energy demand and supply (Jamilatun et al., 2025). This situation requires solutions that are not only technical but also educational. In this way, the younger generation can understand the root of the problem and contribute to formulating strategies for wiser and more sustainable energy use.

More specifically, physics education in schools has not systematically developed critical thinking skills (Jamil et al., 2024). These skills are necessary because students need to analyze energy data, evaluate the use of technology, consider environmental impacts, or design evidence-based solutions to energy scarcity problems. In this study, critical thinking skills are focused on the five indicators proposed by Facione: interpretation, analysis, evaluation, inference, and explanation. Interpretation refers to students' ability to understand and clarify the meaning of information, data, or problems related to energy. Analysis involves identifying relationships among concepts, information, or evidence to understand energy-related problems. Evaluation refers to students' ability to assess the credibility of information and the strength of the arguments or evidence used to support a solution. Inference involves drawing logical conclusions and proposing appropriate solutions based on available evidence, while explanation refers to students' ability to clearly communicate the reasoning, evidence, and conclusions underlying their decisions or solutions (Facione, 2015). These indicators are highly relevant to the context of renewable energy because students are expected not only to understand physics concepts, but also to interpret energy-related information, analyze problems, evaluate technological alternatives, draw evidence-based conclusions, and explain the solutions they propose.

In addition, the relevance of the physics curriculum adds to the challenges in this field. Traditional curricula often prioritize theoretical knowledge and fail to attract students seeking practical, relevant applications of physics in everyday life (Nyoman et al., 2025). As a result, students rarely practice connecting physics concepts to contexts in everyday life, the environment, or global challenges such as renewable energy. However, this is crucial for physics to be relevant and meaningful. In fact, the

context of renewable energy (e.g., solar panels, energy efficiency, energy conversion can be a broad learning arena for topics such as dynamic electricity, thermodynamics, fluids, waves, or optics that can be directly linked to real-world challenges, such as how to design efficient and environmentally friendly power systems, or understanding the impact of technology on nature. This allows students to learn physics not merely as a collection of abstract formulas, but as a tool for understanding and solving real-world problems.

The limitations of this traditional approach highlight a significant gap between what is needed in the 21st Century and what is provided: the 4C skills (Communication, Collaboration, Critical Thinking and Problem Solving, and Creativity and Innovation) (Dewi et al., 2023). Therefore, the direct integration of renewable energy contexts and sustainability-oriented physics learning is crucial. However, energy concepts are still often taught through conventional approaches that are not yet fully capable of fostering a deep, relevant understanding of sustainability issues (Wahyuni & Novita, 2024). Therefore, systematic action is needed to reformulate the physics curriculum to include sustainability and energy issues. Teachers also need to learn the ability to connect physics concepts with real-world challenges, and learning needs to be directed so that students can be directly involved, not merely as recipients of material, but as critical, creative, and environmentally conscious thinkers.

Several researchers have previously attempted to address this issue through various approaches. (Pattayev et al., 2024) integrating renewable energy into solar panel-based STEAM learning successfully increases students' interest in physics. (Guo et al., 2021) developed a virtual laboratory for studying renewable energy microgrid systems that can raise awareness and understanding of clean energy concepts. (Berliana et al., 2024) effectively applied a STEM-based PjBL model to improve science literacy on the topic of alternative energy. (Ainur & Nadi, 2024) used project-oriented problem-based learning through SR-STEM in an effort to enhance critical thinking skills. (Sari et al., 2025) developed problem-based digital teaching materials combined with the Social-Scientific Issues (SSI) Approach on the topic of renewable energy to improve students' critical thinking skills. (Lia & Herlina, 2024) applied a problem-based learning (PBL) model to enhance students' critical thinking skills in renewable energy subjects in secondary schools. (Rizki et al., 2024) applied a project-based learning (PjBL) model in physics classes, to support Education for Sustainable Development (ESD). Although the seven studies above make significant contributions, there is still no research that directly combines the Development of critical thinking skills with the context of renewable energy to

address energy scarcity issues within comprehensive sustainable physics learning.

Although research on renewable energy and STEM-based physics education continues to evolve, various studies have shown that the context of renewable energy can be used to develop critical thinking skills through e-worksheets, project-based learning, and STEM-based media (Nugraha et al., 2024; Anggraini et al., 2025). However, research that specifically uses the issue of energy scarcity as an authentic context for exploring critical thinking skills remains limited. Furthermore, there has been limited research integrating these issues with Facione's five critical thinking indicators, namely interpretation, analysis, evaluation, inference, and explanation, in sustainability-oriented physics education (Facione, 2015). These five indicators enable students to understand information, analyze problems, evaluate evidence and alternative solutions, draw conclusions, and explain their reasoning based on evidence.

Given this gap, the novelty of this study lies in the integration of the context of renewable energy and the issue of energy scarcity as an authentic context in sustainability-oriented physics education, specifically exploring Facione's five indicators of critical thinking skills. This approach positions renewable energy not only as a subject of study, but also as a context for real-world problems that encourage students to apply physics concepts to understand and formulate solutions to energy issues. Thus, the study titled "Exploring Critical Thinking Skills for Solving Energy Scarcity Problems: Integrating Renewable Energy Contexts in Sustainable Physics Learning" aims to explore students' critical thinking skills in addressing energy scarcity issues through renewable energy contexts in sustainability-oriented physics learning.

Method

This research was conducted as a survey at State Senior High School 7 in Surabaya in October 2025. The survey was conducted on 33 grade 11 students who had learned about renewable energy in their physics class. The sampling technique used was purposive sampling, with the criterion being that students had received physics instruction related to renewable energy. This technique was chosen to ensure a match between the characteristics of the research subjects and the research objectives. Data collection was carried out using several techniques, namely essay tests to measure students' conceptual understanding, interviews to explore their thought processes and the reasons behind their answers, and observations to see how students applied concepts in learning situations.

This study used a quantitative, descriptive approach. The data were quantitative or converted to

numerical form, so the data description process used descriptive statistics (Ray W. Cooksey, 2020). Descriptive statistics focus on how to collect data and simplify the numbers observed or obtained, in this case, by summarizing and presenting them (Hal & Yuniarti, 2022). Categorizing critical thinking skills in this study is based on the scores of the answers to the questions described in Table 1.

Table 1. Categories of Critical Thinking: Levels of Students

Level of Critical Thinking Skills	Score
Superior (S)	80-100
Above Average (AA)	61-80
Average (A)	41-60
Bellow Average	21-40
Poor (P)	0-20

(Satriawan et al., 2020)

The instruments used in this study consisted of essay questions developed based on six critical thinking skill indicators proposed by Facione, as well as interviews with students and physics teachers. The essay questions were designed to assess critical thinking skills related to renewable energy materials. The critical thinking framework applied was Facione's (2015) framework, which includes six leading indicators: (1) interpretation, which is the ability to understand and describe the meaning contained in experiences, data, events, rules, beliefs, or conditions; (2) analysis, which is the ability to recognize and examine the logical connections between statements, concepts, data, questions, or arguments; (3) evaluation, which is the ability to assess the credibility of information and the logical strength of an argument; (4) inference, which is the ability to construct or draw logical and acceptable conclusions based on relevant information and evidence; (5) explanation, which is the ability to express the results of thinking and justify reasons rationally based on evidence or methods; (6) self-regulation, which is the ability to monitor and correct one's own thinking to ensure valid reasoning. By applying this framework, the study aims to obtain a more comprehensive picture of students' critical thinking skills in understanding and applying the concept of renewable energy in physics learning. Examples of questions are as follows:

5. Pembangkit Listrik Tenaga Sampah (PLTSA) Benowo dapat menghasilkan listrik sebesar 15 MW melalui pengolahan 1.200 ton sampah per hari. Dari kapasitas tersebut, 12 MW dijual kepada PLN, 2 MW digunakan untuk operasional, dan sisanya 1 MW digunakan sebagai cadangan. PLN menggunakan 12 MW untuk menyuplai listrik kepada rumah tangga di wilayah Benowo dan sekitarnya, dengan setiap rumah tangga memiliki daya 900 watt. Hasil survey pemerintah menunjukkan terdapat 10.000 rumah tangga yang berada di wilayah Benowo. Berdasarkan data tersebut, simpulkan apakah daya listrik yang disuplai oleh PLTSA Benowo mencukupi untuk memenuhi kebutuhan listrik seluruh rumah tangga di wilayah Benowo dan sekitarnya? (*Inferensi*)

Figure 1. Example questions for measuring critical thinking skills

The research procedure began with the development of a research instrument consisting of essay test questions based on Facione's critical thinking skills indicators, along with interview guidelines and observation sheets. The developed instrument was then validated through expert assessment by a physics education lecturer. After the instrument was declared suitable, data collection was conducted by administering essay tests to students, conducting interviews, and observing the learning process. The research data were analyzed using the Miles and Huberman model, which includes the stages of data reduction, data presentation, and conclusion drawing. The analysis was conducted to obtain a comprehensive picture of students' critical thinking skills using Facione's framework.

Result and Discussion

Based on data analysis measuring the critical thinking skills of 11th-grade high school students who had received renewable energy materials, using Facione's critical thinking framework, the students' critical thinking skills remained in the low and very low categories across almost all indicators. For further details, see Figure 1.

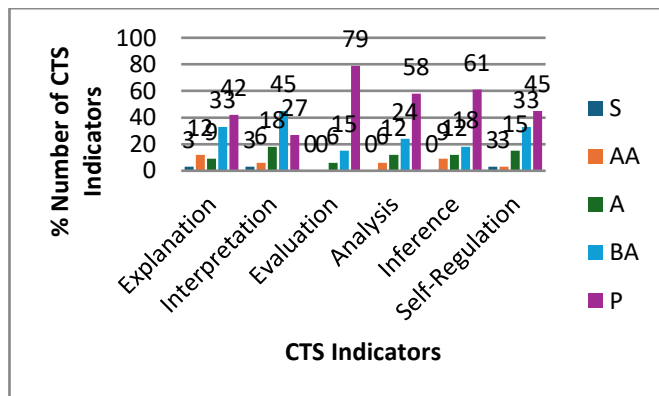


Figure 2. Students' Critical Thinking Skills

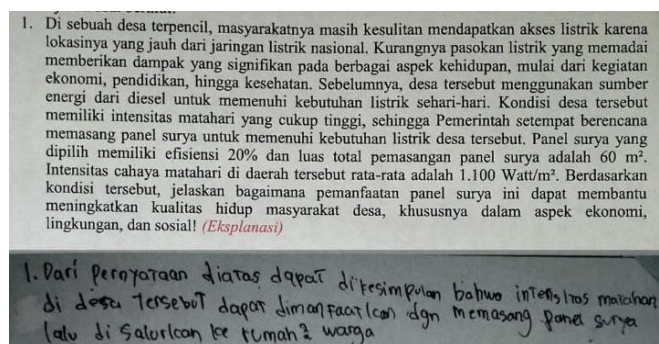


Figure 3. Sample Answers for Explanation Indicators.

The analysis in Figure 2 shows that students' critical thinking skills, as measured by the Explanation indicator, remain in the low category. Only 3% of

students are in the superior category, while 33% are in the below-average category, and 42% are in the poor category. This condition is demonstrated by the students' answers to the following question:

Furthermore, on the Interpretation indicator, the results show that 3% (1 student) is in the superior category, while 45% (15 students) have below-average interpretation skills. Thus, students' critical thinking skills on the Interpretation indicator are still in the low category. This condition is demonstrated through the students' answers to the following question:

2. Sebuah artikel menjelaskan bahwa berkurangnya produksi energi fosil, terutama minyak bumi, serta komitmen global dalam pengurangan emisi gas rumah kaca, mendorong Pemerintah Indonesia untuk meningkatkan peran energi baru dan terbarukan (EBT) secara terus-menerus sebagai bagian dalam menjaga ketahanan dan kemandirian energi. Sesuai PP No. 79 Tahun 2014 tentang Kebijakan Energi Nasional, target bauran EBT pada tahun 2025 adalah paling sedikit 23% dan 31% pada tahun 2050. Indonesia mempunyai potensi EBT yang cukup besar untuk mencapai target bauran energi primer tersebut, seperti terlihat pada Tabel 1.

Tabel 1. Potensi Energi Terbarukan

Jenis Energi	Potensi
Tenaga Air	94,3 GW
Panas Bumi	28,5 GW
Bioenergi	32,6 GW
Surya	207,8 GW
Angin	60,6 GW
Energi Laut	17,9 GW

(Sumber: Ditjen EBTKE, 2018)

Berdasarkan data pada Tabel 1, sumber energi terbarukan apa yang memiliki potensi terbesar di Indonesia? Berikan penjelasan singkat. (Interpretasi)

2. Energi surya memiliki potensi menjadi energi terbesar di Indonesia dikarenakan surya berasal dari panas matahari yang dimana Indonesia secara terus menerus panas dan dapat dimanfaatkan melalui panel surya.

Figure 4. Sample Answers for Interpretation Indicators.

In the Evaluation indicator, only 6% of students were in the average category, while 15% and 79% were in the below-average and poor categories, respectively. The data show that students' critical thinking skills, as measured by the evaluation indicator, are low. This condition is demonstrated through the students' answers to the following question:

3. Pemerintah sedang berupaya mengatasi permasalahan kelistrikan di sebuah desa terpencil yang sulit dijangkau oleh jaringan listrik PLN karena kondisi geografis yang menantang. Untuk mengatasi hal tersebut, pemerintah berencana memasang panel surya sebagai sumber energi alternatif guna mencukupi kebutuhan listrik masyarakat setempat.

Dalam proses pengambilan keputusan, pemerintah mempertimbangkan dua lokasi calon pemasangan panel surya, yaitu Kota A dan Kota B. Masing-masing lokasi memiliki luas wilayah tertentu yang sepenuhnya akan digunakan untuk pemasangan panel surya, serta intensitas cahaya matahari harian yang berbeda. Intensitas cahaya tersebut diasumsikan terjadi secara rata selama 5 jam per hari.

Berikut adalah data dari kedua lokasi dan jenis panel surya yang akan digunakan:



Berdasarkan informasi tersebut, putuskan kombinasi lokasi kota mana dan jenis panel yang paling efisien dan optimal digunakan untuk memenuhi kebutuhan listrik desa tersebut. Berikan alasanmu! (Evaluasi)

2. Lokasi A, karena memiliki intensitas cahaya yang besar dan jenis panel surya : 11- type Back Contact, karena memiliki efisiensi yang

Figure 5. Sample Answer to the Evaluation Indicator

Analysis Indicator: Only 6% of students had above-average analytical skills. Meanwhile, 15% of students had below-average analytical skills, and 79% had poor analytical skills. Thus, students' critical thinking skills, as measured by the analysis indicator, can be categorized as low. This condition is demonstrated through the students' answers to the following question:

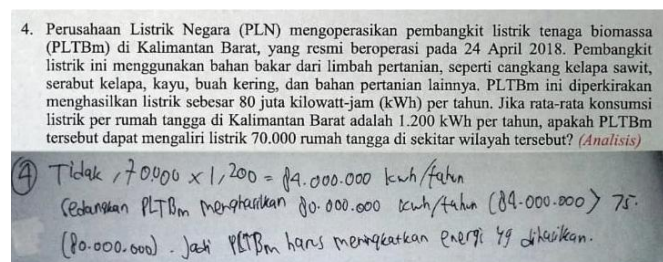


Figure 6. Sample Answers to Analysis Indicators

The inference indicator also showed low results: 18% of students had below-average inference skills, and 61% had poor inference skills. Meanwhile, only 9% of students had above-average inference skills. Therefore, based on this data, students' critical thinking skills, as indicated by inference indicators, can be categorized as low. This condition is demonstrated through students' answers to the following question:

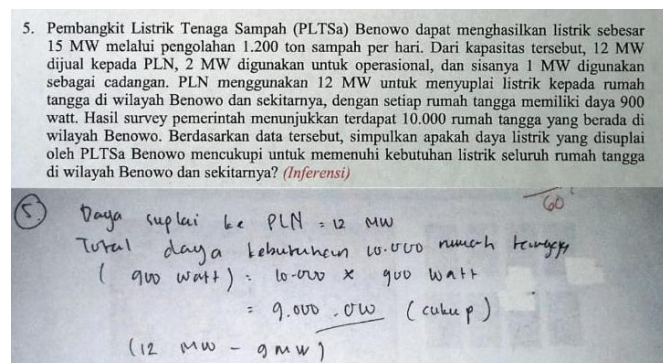


Figure 7. Sample Answer for the Inference Indicator.

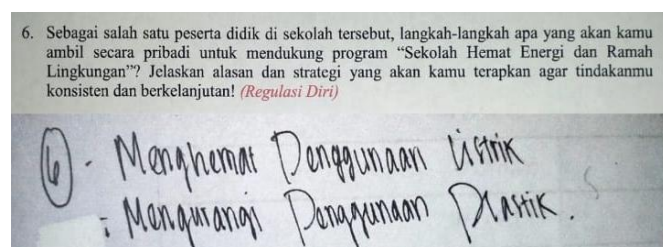


Figure 8. Sample Answer for Indicator 6

The last indicator, Self-Regulation, shows low results: 33% and 45% of students fall into the below-average and poor categories, respectively. Meanwhile, only 3% of students have above-average self-regulation skills. Based on the data, students' critical thinking skills

regarding the self-regulation indicator are low. This condition is demonstrated through students' answers to the following question. Overall, the results indicate that students' critical thinking skills across all Facione indicators remain at a low level after learning renewable energy materials.

The results indicate that students' critical thinking skills across all Facione indicators, Explanation, Interpretation, Evaluation, Analysis, Inference, and Self-Regulation, remain predominantly in the low category. These findings suggest that the learning process has not yet optimally supported the development of higher-order thinking skills.

In the Explanation indicator, students are asked to explain the use of solar panels from an economic, environmental, and social perspective (Figure 3). Although most students can answer the question, their responses are brief and do not include the requested aspects. Students only rewrite the theory without explaining the relationship between concepts, thus not showing their reasoning process. As stated by (Facione, 2015) an explanation describes the basis of reasoning supported by evidence, ideas, methodology, criteria, and context, while presenting this reasoning in the form of logical and convincing arguments.

Regarding the Interpretation indicator (Figure 4), question number 2 asks students to cite data from the Table provided in the question and explain in depth the reasons for the potential based on geographical location and solar intensity. Figure 4 shows that students were able to complete the question, but did not specify which data were relevant or explain their reasoning in depth. This indicates that students had difficulty understanding the information in the question, including identifying what was known, what was being asked, and the meanings of the problem's concepts. Similar to what was stated by (Facione, 2015), interpretation is the ability to understand, clarify, and recognize the meaning or significance contained in various experiences, situations, data, events, assessments, conventions, beliefs, rules, procedures, and criteria. Inability at this stage causes continuous errors in the analysis and problem-solving process.

For the Evaluation indicator (Figure 5), question 3 asks students to determine which combination of city locations and panel types is most efficient and optimal for meeting the village's electricity needs. However, the students' answers do not provide a clear decision on which combination is most efficient, nor do they explain the reasons or considerations behind their choices. The answers provided are mostly general statements, without detailed explanations of the factors that affect efficiency, such as the intensity of sunlight at each location, the type of solar panels used, and relevant environmental conditions. The reason for the low level

of evaluation skills is that students are not accustomed to being asked questions that require them to assess whether a statement is true in solving a problem. They are also not accustomed to concluding these statements (Facione, 2015).

In the Analysis indicator (Figure 6), question 4 asks students to analyze average household electricity consumption. The results show that most students can perform basic calculations, but the steps for solving the problem are not wholly or systematically organized. Students did not record the "known" and "unknown" parts, did not clearly show the calculation steps, and did not compare or draw conclusions from the results. This indicates that although students understand the basic concepts of calculation, they still find it challenging to present their thinking and analysis in a structured, argumentative manner, which is an integral part of critical thinking. The reason for the low level of analytical skills among students is that they are more often given numerical problems and are only asked to solve them using mathematical formulas. Students also more often solve problems with explicit formulas (Sarip, Arafah, 2022). To improve their evaluation skills, students need to apply appropriate, comprehensive, and correct problem-solving strategies (Susanti, 2016).

The Inference indicator (Figure 7), question number 5, asks students to conclude whether the electricity generated by the Benowo PLTSa is sufficient to meet the electricity needs of all households in the Benowo area and its surroundings. The students' answers show that the majority can perform basic calculations correctly, but are not yet able to present the solution process in a structured and complete manner. Many students did not include initial information such as the "known" and "asked" sections, nor did they record the calculation steps or detailed comparisons of the results. In addition, most of the answers lacked a clear conclusion on the adequacy of the generated electricity. This condition shows that, although students understand the basic concepts, they still have difficulty communicating their thought processes logically and drawing conclusions from the data obtained. Some students are still unable to conclude from the provided context, and some do not even understand the conclusions that can be drawn from the problems presented (Lusiana et al., 2022). The inference indicator describes how students make appropriate conclusions to solve problems.

In the Self-Regulation indicator (Figure 8), question number 6 asks students to explain the personal steps they can take to support the "Energy-Efficient and Environmentally Friendly School" program, along with the reasons and strategies to ensure that these actions are consistent and sustainable. The students' answers show that most wrote only the steps they would take, without

explaining the reasons or supporting strategies (Qohar & Sulandra, 2021). This suggests that the students' self-regulation skills are still relatively low, as they are not yet able to reflect on and plan their actions. This condition shows the need for learning that encourages self-reflection and metacognitive awareness, so that students can think more deeply and take responsibility for their decisions. The students did not recheck their calculations, did not correct errors even when discrepancies were found, and did not evaluate their solution strategies. Facione emphasizes that self-regulation involves a person's awareness of their own cognition, the elements used in the thinking process, and the results obtained, primarily through the application of skills for evaluating students' abilities to conclude in the form of questions, confirmation, validation, and correction.

In addition, low critical thinking skills are influenced by other factors, including students' lack of thoroughness, failure to focus on the question's context, and inability to correctly recognize and select relevant information in the question. In addition, students still experience misunderstandings. The causes of students' difficulties in solving these questions affect the outcomes of their critical thinking skills (Rosdiana & Kusairi, 2019). In addition, learning habits hinder the Development of critical thinking skills, as students tend to feel comfortable accepting teachers' explanations without questioning them further (Priyadi et al., 2018).

Based on the results of interviews and observations conducted during the classroom learning process so far, it still lacks skills, including critical thinking. The learning process is still carried out conventionally, with assignments completed independently and then presented in class. In addition, the classroom learning design still does not reflect learning that involves specific skills. There are several limitations to this study, including a small sample size, a focus on renewable energy materials, and the absence of direct learning interventions, which limit the generalizability of the results. For further research, it is recommended to experimentally test innovative learning models, expand the number and variety of samples, use more comprehensive assessment instruments, and integrate learning technologies such as virtual laboratories to gain a deeper understanding of efforts to improve students' critical thinking skills.

Conclusion

Based on the study's results, students' critical thinking skills in physics, especially in renewable energy materials, remained in the low to very low range across all Facione indicators, including interpretation, analysis, evaluation, explanation, inference, and self-regulation. Students tended to give incomplete, unstructured

answers with minimal arguments, indicating that they were still unable to process information in depth or draw logical conclusions. These findings suggest a need for more context-based physics learning, problem-solving oriented, and integrated with renewable energy issues, to encourage the Development of critical thinking skills. In addition, teachers also need to use innovative learning approaches and receive special training to facilitate the Development of critical thinking skills through open-ended questions, projects, and analytical discussions. Operationally, the results of this study imply the need for physics learning that utilizes contextual problems involving renewable energy and open-ended questions to train students' abilities in analyzing, evaluating, and drawing data-based conclusions. Teachers are advised to implement analytical discussions and project-based assignments. Further research should test the effectiveness of renewable energy-based physics learning models through experimental designs.

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