Measuring learners' critical thinking skills using argument-based assessment on the issue of global warming

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Abstract
The low level of students' critical thinking and argumentation skills has attracted attention. This study aims to analyze the improvement of students' critical thinking skills by implementing argumentation-based assessment as an innovative learning strategy. The method used is a quantitative descriptive study involving 28 grade XI MIPA students, using essay tests and questionnaires as data collection instruments. Data were analyzed descriptively and inferentially through N-gain calculations and paired t-tests to measure the improvement of critical thinking skills. The results showed an increase in critical thinking skills from the poor and sufficient categories in the pre-test stage to good and very good categories in the post-test stage, with an average N-gain of 55% which is included in the moderate category and a paired t-test significance value <0.05 which indicates a significant difference. These findings demonstrate the effectiveness of argumentation-based assessment in developing critical thinking skills while contributing to the development of relevant contextual learning strategies to improve scientific literacy and meet the demands of 21st-century competencies.

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1. Introduction

Global warming is a significant global issue, affecting many aspects of life and the environment. The increase in the Earth's average temperature due to greenhouse gas emissions is causing extreme climate change, melting polar ice caps, and rising sea levels (IPCC, 2021). The importance of young people's understanding and involvement in this issue emphasizes the need to develop critical thinking skills among learners. These skills are essential to help learners analyze information, evaluate arguments, and make decisions based on scientific evidence, which plays an important role in preparing learners to develop 2 st century competencies. 21st century learning must be able to support the development of soft skills and character, focus on essential material, and provide flexibility in the learning process. Integration of the 4C concept, namely creativity and innovation, collaboration, communication, and critical thinking and problem solving. According to Zairina and Hidayati (2022) showed that the quality of argumentation skills. Junior high school students on global warming material are still at levels 1 and 2, with relatively low ability to argue, analyze, and evaluate information. Thus, this ability can hinder students from understanding concepts correctly and appropriately on environmental issues. Students' critical thinking skills in physics learning are still a problem that is often found and has been widely studied in various studies. Based on preliminary findings in several schools, students show difficulty in linking physics concepts with events that occur in real life, and are not accustomed to compiling logical arguments in problem solving.

Zubaidah (2018) states that the critical thinking skills of students in Indonesia are still at a low level, especially in the aspects of interpreting, analyzing, and evaluating scientific information. This is reinforced by the results of research by Nugraha et al. (2020) which revealed that in science learning, only about 35% of students can express opinions logically supported by scientific data and evidence. These facts indicate the importance of mapping the profile of students' critical thinking skills in more depth. For this reason, it is necessary to carry out an appropriate measurement or analysis process. In the research of Satriawan, et al (2020). Obtained the results of the analysis that the thinking skills of prospective physics teacher students on all critical thinking indicators were still at a level below the average. This shows that critical thinking skills in Indonesia are still at a low stage which allows students to be in difficulty. A number of previous studies have been conducted to evaluate and analyze students' critical thinking skills in the context of physics learning. Ika (2020) found that the application of the Argument Based Science Inquiry (ABSI) model can effectively encourage

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the improvement of students' critical thinking skills. Other research by Nurjanah et al. (2022) and Ardiyanti and Nuroso (2021) showed that students' critical thinking skills were still at a low level, especially when studying materials such as dynamic fluids and the laws of motion. Cesariyanti et al. (2022) highlighted the role of virtual laboratories based on the PODE model in developing critical thinking skills. On the other hand, Suganda et al. (2021) and Muna & Linuwih (2023) noted that in wave, light, and thermodynamic materials, most students have not shown optimal critical thinking skills. Some additional research, such as those conducted by Priyadi et al. (2025) and Sa'adah et al. (2021), indicate that the Socioscientific Issues (SSI) approach can help trigger critical thinking skills, although it has not been specifically linked to argument-based assessment. However, until now no research has been found that specifically focuses on measuring students' critical thinking skills through argument-based assessments in the context of global warming issues. The majority of previous studies prioritize the effect of learning models or critical thinking skills in conventional physics materials without linking them directly to actual global issues. Therefore, this research has the value of novelty and originality, because it offers an alternative approach that unites argument-based assessment with the context of globally relevant environmental issues. This approach is expected to not only improve critical thinking skills, but also build learners' scientific awareness of the real challenges of the 21st century.

Based on a review of these studies, no research has been found that specifically develops or measures students' critical thinking skills using argument-based assessment in the context of global warming issues. Most studies still use conventional approaches or general instruments without explicitly linking them to global issues that are complex and multidisciplinary (Ajid et al., 2025; Khan, 2024). Strong novelty and originality. This research not only integrates the context of global environmental issues that are relevant to real life, but also uses an argument-based assessment approach designed to deeply explore students' ability to critically assess, compose, and defend scientific arguments. This research is expected to make theoretical and practical contributions in the development of critical thinking skills assessment models that are more contextual, applicable, and relevant to the challenges of the 21st century (Lintangesukmanjaya et al., 2025). The novelty of this research lies in the development of an argument-based assessment specifically used to measure students' critical thinking skills in the context of global warming, something that has not been widely researched before. This research integrates assessment with complex and multidisciplinary global issues, thus providing a more contextual and applicable picture of critical thinking skills. Furthermore, this approach has the potential to become an innovative assessment model that supports students' scientific literacy and environmental awareness in line with the demands of 21st-century learning.

The critical thinking skills trained through the stages of argumentation-based assessment on the issue of global warming have broad implications for students' science literacy. Good science literacy enables learners to understand the relationship between science concepts and everyday life, so that they are able to make wise and responsible decisions (OECD, 2021). By equipping learners with critical thinking skills, learners are expected to become environmentally conscious individuals who are able to provide innovative solutions to global challenges. By thinking critically, learners are not only able to analyze and evaluate arguments, but also review the1w thought processes used to ensure their veracity. Physics is a strategic subject in practicing this skill, as it involves logical, systematic, analytical, creative and collaborative thinking that results in rational conclusions (Noveski et al., 2024; Tay & Eng, 2024). Based on this explanation, the researcher aims to measure students' critical thinking skills through argument-based assessment in the context of global warming issues, so as to obtain a real picture of their critical thinking abilities in dealing with science problems that are relevant to the issues that occur.

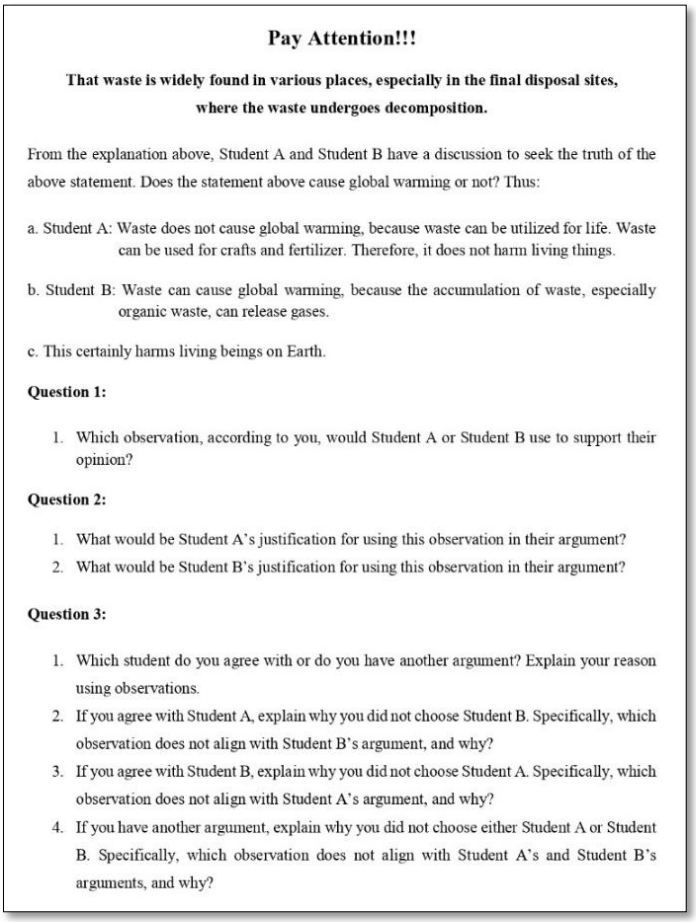
Based on this background, the purpose of this study is to analyze students' critical thinking skills through the application of argument-based assessment in the context of global warming issues. This study is specifically designed to map students' abilities in constructing, disseminating, and defending scientific arguments relevant to real-life environmental issues, thereby providing a more in-depth picture of their level of mastery of critical thinking skills. This approach has novelty value because it not only measures critical thinking skills in general, but also integrates them with complex and multidisciplinary global issues, while developing an assessment model that is contextual, applicable, and relevant to the challenges of 21st-century learning. The results of this study are expected to provide theoretical and practical contributions in efforts to improve scientific literacy and environmental awareness of students through physics learning based on scientific argumentation.

2. Method

This research uses descriptive quantitative methods by using survey research, namely essay tests and observation as data collection instruments. Questions were designed according to critical thinking indicators: Observe, Analyze, Synthesize, Summarize, and Evaluate (Faiz, 2023). This research was conducted through several systematic stages, starting from planning, developing argument-based assessment instruments, expert validation, limited trials, conducting the main research, to data analysis and interpretation of results. The instrument developed was in the form of contextual argument-based questions that raised the issue of global warming as a stimulus to measure students' critical thinking skills. This study involved 28 purposive samples based on the research needs, enabling the researchers to obtain in-depth and relevant data (Saidawati et al., 2022). The results of this study were generalized in an exploratory manner to provide an initial overview of

students' critical thinking skills in the context of argument-based assessment. This approach was chosen to explore the potential for developing a contextual assessment model that is appropriate to the challenges of 21st-century learning.

The instrument includes critical thinking indicators such as identifying arguments, evaluating evidence, drawing logical conclusions, and constructing coherent arguments. Before being used in the main research, the instrument was validated by experts in physics education and evaluation measurement, and went through a limited trial to ensure its quality. The validation results showed that the instrument had a high level of content validity (Flake et al., 2022). In addition, the reliability test was conducted using Cronbach's Alpha formula and resulted in a reliability coefficient value of > 0.7, indicating that the instrument was reliable and feasible to use. The research data were obtained from the results of the critical thinking skills assessment given to two groups of students, namely the experimental group using argument-based assessment and the control group using conventional assessment. The data analysis technique was carried out quantitatively using an independent t-test to determine the significance of the difference between the two groups. The t-test results showed that there was a statistically significant difference ($p < 0.05$) between the results of students' critical thinking skills in the experimental and control groups, which means that the argument-based assessment was more effective in measuring and encouraging critical thinking skills. The instruments used are shown in Figure 1.



Pay Attention!!!

That waste is widely found in various places, especially in the final disposal sites, where the waste undergoes decomposition.

From the explanation above, Student A and Student B have a discussion to seek the truth of the above statement. Does the statement above cause global warming or not? Thus:

a. Student A: Waste does not cause global warming, because waste can be utilized for life. Waste can be used for crafts and fertilizer. Therefore, it does not harm living things.

b. Student B: Waste can cause global warming, because the accumulation of waste, especially organic waste, can release gases.

c. This certainly harms living beings on Earth.

Question 1:

1. Which observation, according to you, would Student A or Student B use to support their opinion?

Question 2:

1. What would be Student A's justification for using this observation in their argument?
2. What would be Student B's justification for using this observation in their argument?

Question 3:

1. Which student do you agree with or do you have another argument? Explain your reason using observations.
2. If you agree with Student A, explain why you did not choose Student B. Specifically, which observation does not align with Student B's argument, and why?
3. If you agree with Student B, explain why you did not choose Student A. Specifically, which observation does not align with Student A's argument, and why?
4. If you have another argument, explain why you did not choose either Student A or Student B. Specifically, which observation does not align with Student A's and Student B's arguments, and why?

Figure 1. Test instrument

Data were analyzed using descriptive statistics by categorizing critical thinking skills presented in Table 1.

Table 1. Levels of Critical Thinking Skills

Criteria	Percentage
Less than Once	0 - 20
Less	21 - 40
Simply	41 - 60
Good	61 - 80
Very good	81 - 100

To measure the quality of students' argumentation, an argumentation assessment framework by Erduran et al. (2004) was used as shown in Table 2.

Table 2. Argumentation Level Assessment Framework

Level	Criteria
1	Argumentation consists of simple claims against replies or claims with claims.
2	Argumentation consists of claims with good data, warrant, or backing, but does not contain any refutation.
3	Argumentation consists of a series of claims with good data, warrant, or backing with very weak rebuttals.
4	Argumentation shows claims with clearly identified counterclaims. The argument may have several claims and counterclaims, but this is not required.
5	Argumentation features a long statement with more than one refutation.

3. Results and Discussion

Based on data collection through essay tests and observations of students who took part in argumentation-based assessments on the issue of global warming, the quality of students' argumentation based on the argumentation assessment framework (Erduran et al., 2004), it was found that:

a. Level 1: Learners' argumentation that makes simple claims without data support or refutation, about 30% of all learners.

b. Level 2: Dominate i.e. around 40% of learners are able to construct arguments by including claims, data, or warrants, but have not included adequate rebuttals.

c. Level 3 and higher: Only about 30% of learners show a more complex argumentation structure with rebuttals, albeit in limited numbers, and only a minority reach level 4 or 5.

The test results of students in the form of critical thinking skills scores and their categories at the beginning of learning, namely the pre-test, can be seen in Table 3.

Table 3. Pre-test Score Distribution Results

Value	Total	Category
25	16	Less
50	11	Simply
75	1	Good
100	0	Very good

In general, most students showed critical thinking skills at the "Less" to "Fair" level. The percentage distribution of critical thinking skills acquired is shown in Figure 2.

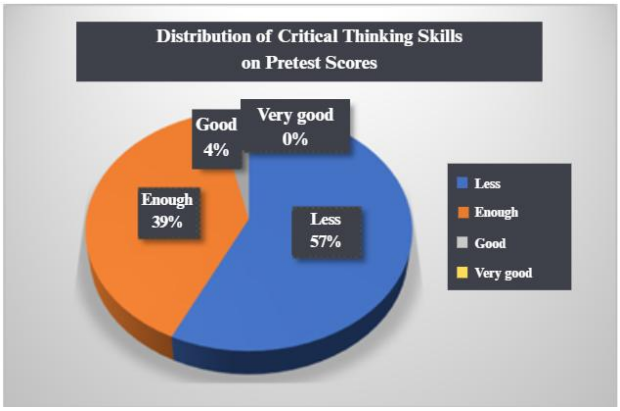


Figure 2. Category Distribution of Critical Thinking Skills of Learners on Pre-test Values.

When viewed from the indicators of critical thinking skills, namely (1) providing interpretation or initial observation of information, (2) analyzing arguments, (3) synthesizing and connecting data, (4) drawing conclusions, and (5) evaluating arguments or information (Facione, 1990). The results on each indicator can be seen in Figure 3.

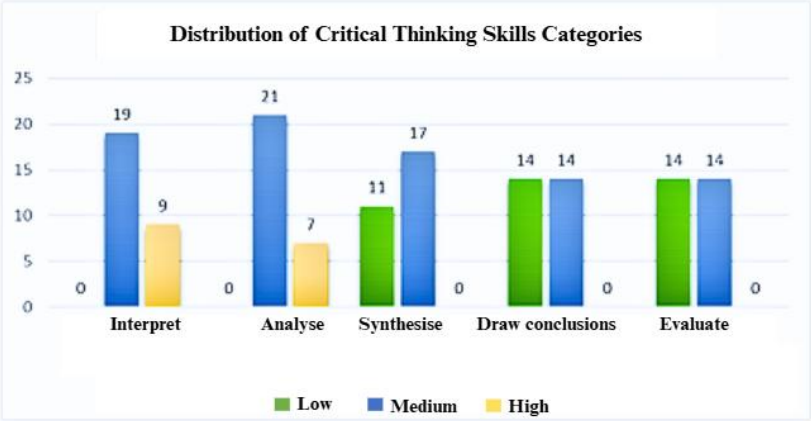


Figure 3. Results on each indicator (Pretest)

Based on graph 1 at the pre-test stage, the majority of students only showed performance at the simple observation and analysis stages, namely the interpretation and analysis indicators which were dominated by the medium to high categories. While for other indicators that show a higher level of critical thinking and argumentation, the results of students are dominated in the medium and even low categories. So that these results affect the overall distribution of pre-test scores obtained, namely in the "Poor" and "Fair" categories. After learning with assessment-based tests, a test is carried out at the end of learning, namely the post-test. The results of students' post-test scores can be seen in Table 4.

Table 4. Post-test Score Distribution Results

Value	Total	Category
25	0	Less
50	8	Simply
75	16	Good
100	4	Very good

In general, most students showed improved critical thinking skills from the pre-test results, namely at the "sufficient", "good" to "very good" levels. The percentage distribution of critical thinking skills obtained is shown in **Figure** 4.

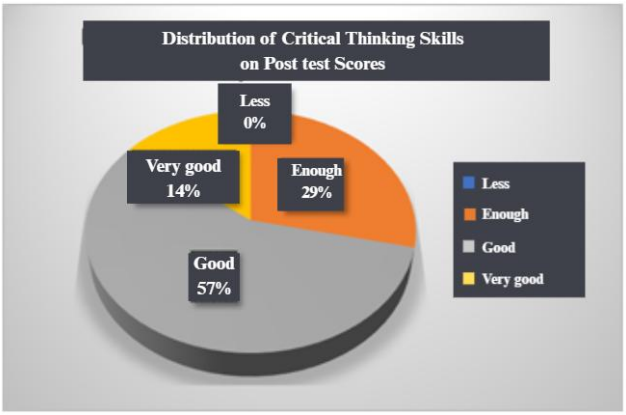


Figure 4. Category Distribution of Critical Thinking Skills of Learners on Post-test Values

The data shows that after the application of argumentation-based assessment, most students experienced an increase in the level of thinking in the form of critical thinking skills, especially in the ability to analyze and synthesize information. This can be seen from the results obtained by students on each indicator of critical thinking skills shown in Figure 5.

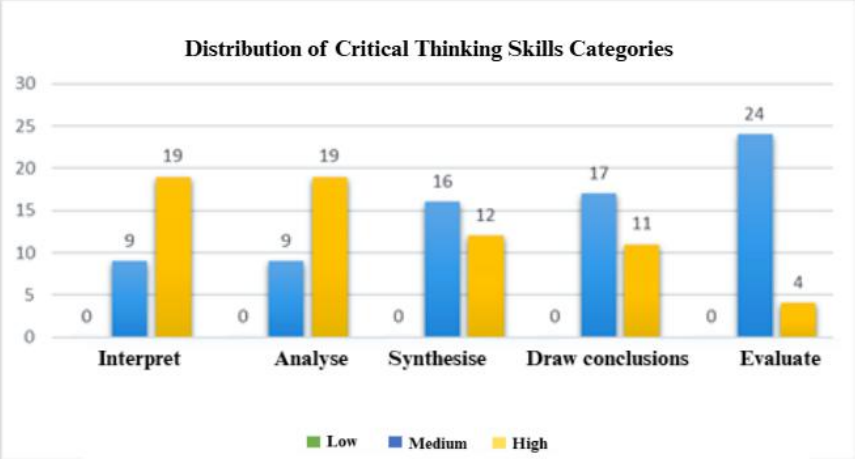


Figure 5. Results on each indicator (post-test)

Based on graph 2, it can be seen that the level of thinking in the form of critical thinking skills of students has increased, this can be seen from the categories obtained in each indicator, namely in the medium to high category and none are in the low category. The improvement of students' critical thinking skills can also be seen from the results of the N-gain analysis and paired t test shown in Table 5 and Table 6.

Table 5. Results of Pre-test, Post-test, and Calculation N-gain.

Test	Min Value	Max Value	Average	Mean Ngain (%)	Category
Pre-test	25	75	36,6	55	Medium
Post-test	50	100	71,4		

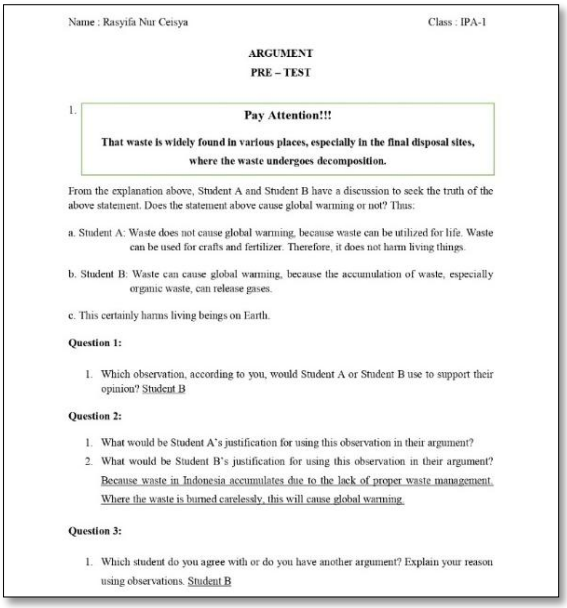
Based on Table 5, the results show that students' critical thinking skills increase with an average N-gain of 55% and are categorized as moderate.

Table 6. Paired t-test results

				99% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pretest-Posttest	-34.8214	18.4332	3.4835	-41.9691	-27.6738	-9.996	27	0.000

Based on Table 6, it can be seen that the paired t test results obtained sig (2-tailed) results of 0.00 and less than 0.05, thus indicating that there is a significant difference between the pre-test and post-test results. These results are in line with the research of Ramona R et.al (2023) which states that argument-based test instruments can improve students' critical thinking skills as evidenced by the average N-gain of 57% in the moderate category. The results showed that the application of argumentation-based assessment provides a comprehensive picture of students' critical thinking skills. Quantitative data from essay tests and observations indicate that learners' abilities are still low, especially in the aspects of analysis and synthesis of information, these two indicators are important roles of the critical thinking framework according to Ennis (1985) so they still need to be improved. This finding is in line with previous research which suggests that students' critical thinking skills, especially on the issue of global warming, are still at a relatively low level (Zairina & Hidayati, 2022; Satriawan et al., 2020).

When viewed from the indicators of critical thinking skills, namely (1) providing interpretation or initial observation of information, (2) analyzing arguments, (3) synthesizing and connecting data, (4) drawing conclusions, and (5) evaluating arguments or information (Facione, 1990). Where, at the initial stage, the majority of students only showed performance at the observation and simple analysis stages. This can be seen from the answer of a learner named Rasyifa in Figure 6.



Name : Rasyifa Nur Ceisya Class : IPA-1

ARGUMENT
PRE – TEST

1. **Pay Attention!!!**

That waste is widely found in various places, especially in the final disposal sites, where the waste undergoes decomposition.

From the explanation above, Student A and Student B have a discussion to seek the truth of the above statement. Does the statement above cause global warming or not? Thus:

a. Student A: Waste does not cause global warming, because waste can be utilized for life. Waste can be used for crafts and fertilizer. Therefore, it does not harm living things.

b. Student B: Waste can cause global warming, because the accumulation of waste, especially organic waste, can release gases.

c. This certainly harms living beings on Earth.

Question 1:

1. Which observation, according to you, would Student A or Student B use to support their opinion? Student B

Question 2:

1. What would be Student A's justification for using this observation in their argument?
2. What would be Student B's justification for using this observation in their argument? Because waste in Indonesia accumulates due to the lack of proper waste management. Where the waste is burned carelessly, this will cause global warming.

Question 3:

1. Which student do you agree with or do you have another argument? Explain your reason using observations. Student B

Figure 6. The answer of one of the students.

The learner named Rasyifa gave the answer "Agreeing with one of the two statements given, namely agreeing with student B only by providing simple and less strong arguments." The results obtained by these learners can be seen from the distribution of pre-test scores which are dominated by the "Poor" and "Fair" categories. Thus, their ability tends to state information without supporting data or strong justification, In the context of improving science literacy, the use of an argumentation approach is proven to provide space for learners to hone their ability to develop evidence-based arguments. By involving critical thinking indicators such as Observation, Analysis, Synthesis, Inference, and Evaluation, learners are encouraged to not only passively receive information, but actively review and criticize existing data. This approach supports the integration of the 4C concept (creativity, collaboration, communication, and critical thinking), which is an essential competency in 21st century learning. The results of most learners at the beginning of learning still show abilities that are at the "Poor" to "Fair" level. After learning the results of the final test of students there is an increase in the quality of argumentation in the group of students who have received additional guidance through argumentation-based assessment. This also affects the critical thinking skills of students who are at the "Fair", "Good", and even "Very Good" levels. The improvement in the quality of students' arguments can be seen in the emergence of argumentation at level 3 and above, where students begin to be able to identify and include refutations in their arguments. This can be seen in the answers of learners named Aisyah in questions 1 and 2 in Figure 7.

Name : Aisyah Rahmaulidia Class : IPA-1

ARGUMENT
PRE – TEST

1. **Pay Attention!!!**

That waste is widely found in various places, especially in the final disposal sites, where the waste undergoes decomposition.

From the explanation above, Student A and Student B have a discussion to seek the truth of the above statement. Does the statement above cause global warming or not? Thus:

a. Student A: Waste does not cause global warming, because waste can be utilized for life. Waste can be used for crafts and fertilizer. Therefore, it does not harm living things.

b. Student B: Waste can cause global warming, because the accumulation of waste, especially organic waste, can release gases.

c. This certainly harms living beings on Earth.

Question 1:

1. Which observation, according to you, would Student A or Student B use to support their opinion? Student A and student B

Question 2:

1. What would be Student A's justification for using this observation in their argument? Because waste can be processed and managed in such a way that it can be reused.
2. What would be Student B's justification for using this observation in their argument? In the absence of proper waste management in Indonesia, waste tends to accumulate, which can result in the spread of diseases and decomposition.

Question 3:

1. Which student do you agree with or do you have another argument? Explain your reason using observations. Student A and student B

Figure 7. Answer from one of the students.

The learner named Aisyah gave the answer "agree with the statements of students A and B because the two things contained in the statement are the causes of global warming and the learner can provide arguments accompanied by in-depth solutions." Based on the learners' answers, it shows that the approach used in learning, especially in this study, has the potential to develop critical thinking skills, although it requires more significant improvement through more intensive and integrated learning strategies that not only focus on content, but also provide space for systematic argumentative exploration, such as through debates and discussions based on existing issues. Summary of research data can be seen in Table 7.

Table 7. Summary of research data

Indicator	High	Medium	% High	% Medium
Interpretation	19	9	67.9	32.1
Analyzing	19	9	67.9	32.1
Synthesize	12	16	42.9	57.1
Draw conclusions	11	17	39.3	60.7
Evaluate	24	4	85.7	14.3

Based on the research results in Figure 7, the analysis of argumentation-based critical thinking skills shows a diverse distribution of achievements in each indicator. In the interpretation indicator, 19 students were in the high category, indicating that most students have been able to understand and give meaning to the information about global warming presented. This achievement is in line with the findings of Nuraini et al. (2021) who stated that interpretative exercises in the context of scientific argumentation can strengthen understanding of complex issues. The analyzing indicator shows that although the majority of students (19 people) are already in the high category, there are still 9 students who are in the medium category, indicating difficulties in parsing and assessing the relationship between factors causing global warming (Nuraini et al., 2021). This finding is reinforced by the results of Maharani & Huda's research (2022) which states that analytical skills are still a major challenge in learning that requires critical and systematic processing of information (Maharani & Huda, 2022).

Most students only reach levels 2–3 in Erduran's argumentative framework because their critical thinking skills are limited to expressing basic claims and reasons without strong scientific evidence or consideration of counterarguments. Low exposure to argumentation-based learning and minimal practice in integrating data, concepts, and scientific reasoning make it difficult for students to construct complex arguments. Furthermore, a learning culture that focuses more on memorization and single answers hinders the development of higher-level argumentation skills that require critical reflection and multidimensional thinking. This is certainly influenced by findings from students' critical thinking skills, where critical thinking skills are also related to their argumentation skills (Meral et al., 2021).

Meanwhile, in the synthesizing indicator, 16 students were in the medium category, while the other 12 were in the high category. This reflects that students still face difficulties in integrating information from various sources into a coherent argument. This finding is consistent with the research of Pratiwi and Kurniawan (2023) who found that students need intensive practice in connecting various concepts and information into a unified understanding. On the indicator of drawing conclusions, 17 students were in the medium category and 11 students in the high category. Students' answers show that even though they can draw conclusions, there are still shortcomings in underlying these conclusions with strong evidence and reasons (Pratiwi & Kurniawan, 2023). This is in line with the results of Sari & Fauzan's (2020) study which shows that the ability to conclude with strong logic and evidence is still an important developmental area in contextual science learning.

The evaluating indicator showed the most prominent results, with 24 students in the high category. Students' answers indicate the ability to assess the strengths and weaknesses of an argument and formulate constructive criticism of various perspectives (Sari & Fauzan, 2020). This result is supported by the research of Yuliana et al. (2021) which states that argumentation-based learning and critical reflection are effective in improving students' evaluative skills (Yuliana et al., 2021). Overall, this achievement trend reflects the hierarchy of critical thinking skills as described by Anderson & Krathwohl in the revision of Bloom's Taxonomy, but is reinforced by contemporary studies such as Hasibuan et al. (2020), which emphasize the importance of an integrated approach between content, context, and higher-order thinking skills in teaching (Hasibuan et al., 2020). Achievement trends across indicators can be seen in Figure 8.

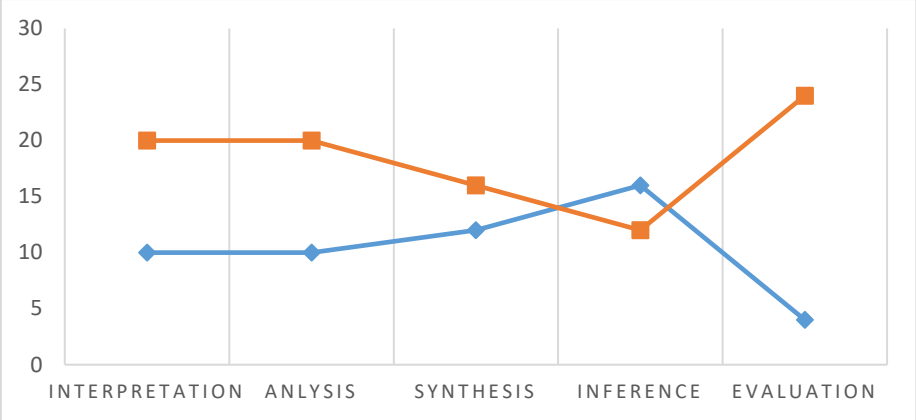


Figure 8. Achievement trends across indicators

In the global warming material used, students can generally answer and solve problems according to the achievement trends across the indicators above. Global warming material is considered difficult because it is complex, multidisciplinary, and requires an understanding of interrelated concepts in physics, chemistry, biology, and scientific data to comprehensively explain the phenomenon (Arshad, 2024). This complexity demands critical thinking skills, according to Facione, such as interpretation to understand climate data, analysis to identify cause-and-effect relationships, inference to predict impacts, and evaluation to assess the accuracy of information and arguments. Without mastery of these skills, students tend to have difficulty integrating information and making evidence-based decisions. This demonstrates the need for argumentative-based learning to train deeper critical thinking on global issues (Grumney, 2022). For example, in the mechanism of the greenhouse effect and its relationship to Earth's energy balance, because it requires an understanding of physics concepts (radiation, heat transfer), chemistry (greenhouse gases), and quantitative scientific data. Without a thorough conceptual analysis, students will not be able to solve problems.

In addition to thinking skills, the difficulties students faced in understanding global warming as revealed in this study are closely related to several key factors. Learning habits that tend to be oriented towards memorization make it difficult for students to integrate cross-disciplinary concepts to explain complex phenomena such as the greenhouse effect and climate change. A weak understanding of physics concepts, particularly those related to energy, heat transfer, and atmospheric dynamics, limits students' ability to analyze cause-and-effect relationships scientifically (Barashkin et al., 2023; Lintangesukmanjaya et al., 2025). Furthermore, a lack of argumentative practice prevents students from developing data-based arguments, evaluating evidence, or considering counterarguments. These findings underscore the importance of argumentative learning to strengthen students' critical thinking skills in addressing complex global issues.

The implications of these findings indicate that the argumentation-based assessment approach contributes significantly to improving critical thinking skills, especially in the context of socioscientific issues such as global warming. However, the synthesis and conclusion indicators still require strengthening strategies, such as the use of more structured scaffolding as suggested by Fitriyani et al. (2021), as well as the application of various types of argumentation that include ethical, social, and value aspects. Thus, it is recommended that teachers not only focus on data accuracy, but also foster learners' ability to build holistic and reflective arguments that are more meaningful in real-life contexts (Fitriyani et al., 2021). Furthermore, developing a more comprehensive argumentation-based assessment finding instrument integrated with other global issues to broaden the scope of students' critical thinking skills is crucial. Further studies could be directed at measuring the effectiveness of this assessment on a broader scale, involving different populations and educational levels, so that the results can be generalized. Future research could also explore the integration of digital technologies, such as AI-based learning platforms or virtual laboratories, to support a more interactive scientific argumentation process. Thus, the argumentation-based assessment development model not only contributes to improved scientific literacy but also equips students with relevant 21st-century skills to address increasingly complex global challenges.

4. Conclusion

This study demonstrates that the implementation of argumentation-based assessment in the context of global warming not only serves as an effective tool to measure students' critical thinking skills but also actively contributes to their development. The integration of global warming issues into the assessment encourages students to engage with the issues by demanding higher-order thinking, evidence-based reasoning, and reflective decision-making. The findings demonstrate a significant improvement in students' critical thinking and argumentation skills, as indicated by an average N-gain of 55% in the moderate category, in addition to paired t-test results showing a statistically significant difference between pre-test and post-test scores. These results highlight the potential of argumentation-based learning to bridge the gap between theoretical knowledge and its practical application, fostering deeper conceptual understanding and scientific literacy. This study

contributes to the design of contextually relevant and pedagogically innovative assessment models, paving the way for future educational practices aimed at equipping students with essential 21st-century competencies to critically evaluate complex environmental issues and actively and sustainably address them.

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