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Enhancing critical thinking through differentiated challenge-based STEM context learning integrated AI-website: An analysis of adversity quotient

Wahid Jauhari[1*], Adi Satrio Ardiansyah[1], Eny Agustianingsih[2]

[1] *Universitas Negeri Semarang, Indonesia*
[2] *SMPN 30 Semarang, Indonesia*

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ABSTRACT

Society 5.0 transforms education, urging students to develop their critical thinking for complex problems. Indonesia's low proportion of students with these skills highlights the need to develop learning innovations. Beyond innovations, this research also considers affective factors like the Adversity Quotient in their impact on critical thinking. On the other hand, there has been no research that integrates Challenge-Based STEM Context Learning, AI-Websites, and differentiated learning simultaneously and examines the influence of AQ within that framework. Therefore, this study aims to determine the effectiveness of differentiated CBL-STEM Context learning integrated by AI-Website to improve critical thinking skills, analyze the influence of AQ on critical thinking skills, and describe those critical thinking skills based on the students' AQ categories. This research used a mixed-method with a sequential explanatory design in all eighth-grade students at one of the state junior high schools in Semarang, represented by two sample groups. Conducted over four weeks, it collected quantitative data through tests and questionnaires, and qualitative data via interviews. Quantitative data were analysed with R software, while qualitative data were condensed and compared to assess critical thinking skills indicators. The results show that the learning model effectively improved students' critical thinking skills, with the experimental group achieving a 75.6% improvement. Regression analysis indicated that the adversity quotient contributed only 8.4% to critical thinking skills in this learning. Field interviews show students meet interpretation and analysis indicators across AQ categories, with differences in other critical thinking areas. This study suggests that similar research should include AQ differentiation in the learning process.

INTRODUCTION

The era of Society 5.0 has brought about significant changes across various sectors. This rapid progression of technology and science in the smart society era fundamentally alters how pedagogical frameworks operate globally (Susilo et al., 2022). Consequently, modern educators face intense pressure to transform conventional methodologies into technology-integrated environments that prepare students for automated societal tasks (Suratmi & Sopandi, 2022). These changes require individuals to adapt by mastering essential twenty-first-century competencies, including critical thinking within the 4C framework. Critical thinking refers to a person's cognitive process in addressing a problem through interpretation, analysis, explanation, evaluation, inference, and self-regulation (Putri et al., 2021). This high-level mental ability is essential for students to make

*Corresponding author: wahidjauhari123@students.unnes.ac.id

Table 1
Percentage distribution of students at levels 4, 5, and 6 in mathematics, 2000 – 2022

Year	Percentage (%) *					
	Level 4	S.E.	Level 5	S.E.	Level 6	S.E.
2000	PISA has not yet assessed mathematics					
2003	1.4	0.4	0.2	0.1	0.0	-
2006	2.8	0.7	0.4	0.2	0.0	-
2009	0.9	0.3	0.1	0.0	0.0	-
2012	1.5	0.5	0.3	0.2	0.0	-
2015	2.7	0.4	0.6	0.2	0.1	0.1
2018	2.3	0.5	0.4	0.2	0.0	0.0
2022	0.5	0.1	0.0	0.0	0.0	0.0

*This percentage refers to the table "Percentage of students at each proficiency level in mathematics" in the PISA mathematics assessment results (OECD, 2005, 2006, 2012, 2013, 2016, 2019, 2023).

reflective, logical decisions when facing complex data (Mustikasari, 2022). In education, critical thinking skills enable students to solve complex problems more accurately (Hamedani, et al., 2024). Recent bibliometric evidence by Khusna et al. (2024) also emphasizes that critical thinking has become a leading focus in mathematics education, underscoring its importance in twenty-first-century learning. This academic consensus shows that improving classroom models is essential for systematically developing students' reasoning and analytical skills (Rensburg & Rauscher, 2022). Therefore, critical thinking has become a crucial competency that students must possess to navigate ongoing societal changes.

Despite being recognized as an essential competence, students' critical thinking skills in Indonesia remain relatively low (Ramlawati, 2025). According to the Program for International Student Assessment (PISA), students who demonstrate strong critical thinking skills are typically classified at Level 4 or above. However, from 2000 to 2022, the proportion of Indonesian students achieving this level has never exceeded 5%. More specifically, the detailed percentages are presented in Table 1**.** This percentage even reached its lowest point in 2022, at approximately 0.5%. This figure is well below the OECD average of 14.9% for high-performing students (OECD, 2022). This low percentage is due to learning that is insufficiently focused on developing critical thinking skills.

One model that supports students' development of critical thinking is Challenge-Based STEM Context Learning, a learning model that presents challenges and problems for students with STEM focused content (Putri et al., 2023). By integrating structured projects and context-rich problems, this approach effectively enhances students' higher-order thinking (Usman, 2024). Additionally, differentiated learning offers varied learning pathways, allowing students with different abilities to reach the same learning goals (Masinading & Gaylo, 2022). This model acknowledges that adapting instructional methods to specific student profiles is critical, as diverse initial skills significantly dictate how learners process complex tasks (Sutama, 2022). This relevance is supported by Shamim et al. (2022), who found that STEM-context pedagogical beliefs are increasingly emphasized as a foundation for developing higher-order thinking skills. Blending digital environments with tailored instructions enhances math skills and reduces cognitive barriers (Nida et al., 2020). As a result, this combination provides a flexible instructional foundation that can be further enhanced by integrating adaptive digital tools. Therefore, using realistic, contextualized situations is vital for enhancing students' math problem-solving skills in modern classrooms (Nugraheni & Marsigit, 2021).

Building on these digital tools, an AI-Website becomes an adaptive innovation that can further facilitate the development of students' critical thinking skills. AI-Website learning supports the development of critical thinking by providing alternative learning pathways to enhance students' learning abilities (Wu, et al., 2025). The structural optimization of integrated web learning platforms substantially accelerates cognitive transformation by encouraging students to dynamically reconstruct visual math representations (Cevikbas & Kaiser, 2022). Website integration also enables the development of flexible features aligned with various learning objectives. However, implementing an AI-Website requires an appropriate learning model to ensure optimal impact on students' critical thinking skills (Omer et al., 2025). A systematic review by Melisa et al. (2025) also concludes that AI integration in higher education can enhance critical thinking, but its impact heavily depends on the learning model used. AI development has shifted many cognitive tasks to digital tools, making critical thinking an even more vital human skill in the Society 5.0 era. As software systems easily automate complex arithmetic computations, modern educational design must prioritize the cultivation of non-mechanized, reflective human reasoning to drive sustainable classroom innovation (Tehlan, 2025). Thus, integrating a differentiated, challenge-based STEM context with an AI website could be an innovation that enhances students' critical thinking skills. In addition to these several factors, there are also internal factors, such as affective factors, that can influence students' critical thinking skills.

One of the affective factors influencing students' critical thinking skills is the Adversity Quotient (AQ) (Astiantari et al., 2022). According to Stoltz (1997), Adversity Quotient is an individual's ability to respond to, endure, and overcome difficulties, measured through the four CORE dimensions: control over situations (Control), responsibility for problems (Ownership), the extent to which difficulties affect other aspects (Range), and endurance in facing obstacles (Endurance). In modern educational psychology, these psychological dimensions are highly structural in defining whether a student will actively search for alternative problem-solving pathways or completely abandon the task (Rahmadani et al., 2025). In the learning context, AQ is related to students' persistence in dealing with complex problems and their tendency not to give up easily. Therefore, AQ can be one of the factors examined in this research to improve critical thinking skills. Consequently, integrating this affective evaluation within a technology-enhanced framework provides a more holistic analysis of the actual mechanics behind student learning development (Chiu, 2022).

Although in theory, AQ is one of the factors that can influence the improvement of critical thinking skills, there has not been much research examining the improvement of critical thinking skills using AQ as one of the variables (Manousou, 2025). Research integrating AI-Websites, CBL-STEM Context and differentiated instruction are still mostly conducted separately, and no studies have examined their integration, resulting in a gap in this topic. Therefore, this study aims to address the research gap by analyzing how students' AQ influences the improvement of critical thinking skills in a differentiated CBL-STEM Context learning integrated with an AI-Website.

Based on this background, the present study was designed to: (1) measure the effectiveness of differentiated challenge-based STEM Context learning integrated AI-Website in improving students' critical thinking skills; (2) analyze the influence of AQ on students' critical thinking skills; and (3) describe students' critical thinking based on their Adversity Quotient categories within mathematics learning. This study is expected to provide an initial overview of the potential of integrating an AI-Website into the CBL-STEM Context, differentiated learning to strengthen students' critical thinking skills in responding to the challenges of the Society 5.0 era.

METHODS

Research design

The research employed a mixed-methods approach using an explanatory sequential design, as outlined by Creswell et al. (2017). The selection of this design is intended to obtain statistical results regarding how learning can effectively improve students' critical thinking skills. This design will also provide a real picture of the statistical results, especially about the students in each AQ category fulfill the critical thinking indicators. This design divides the research into two phases: a quantitative phase and a qualitative phase. The quantitative phase was conducted to statistically measure the effectiveness of differentiated CBL-STEM Context integrated with an AI-website in improving

Table 2
Adversity quotient categorizing

Category	Score Range
Quitter	0 - 94
Camper	95 - 135
Climber	136 - 200

Table 3
Data analysis methods

Analysis Focus	Method	Quantitative Hypothesis
(1)	One-Sample T Test (Mean)	The mean critical thinking test score of the experimental group is greater than the Minimum Competency Criteria (KKTP) of 75.
(2)	Non-Parametric Binomial Test (Proportion)	The proportion of students in the experimental group achieving KKTP is greater than 70%.
(3)	Pair Sample T Test (Mean)	The mean posttest score of the experimental group is higher than its pretest means. The improvement is further described using the students' average N-Gain, calculated as: $N - Gain = \frac{Posttest\ Score - Pretest\ Score}{100 - Pretest\ Score}$.
(4)	Independent Sample T Test (Mean)	The experimental group's mean posttest score is higher than the control groups.
(5)	Mann-Whitney Test (Mean)	The mean N-Gain of the experimental group is higher than that of the control group.

students' critical thinking skills, and to determine the extent of the influence of Adversity Quotient on students' critical thinking skills within this learning environment. Data collected in two groups using a quasi-experiment design to compare differentiated CBL-STEM Context integrated with an AI-website to conventional learning in their ordinary context. Subsequently, the qualitative phase was conducted to describe students' fulfillment of indicators of critical thinking skills during the differentiated CBL-STEM Context learning process integrated with the AI website.

Differentiation in the learning model was implemented through content differentiation, where students received materials tailored to their initial ability levels: high, medium, or low, based on diagnostic test results and their fulfillment of prerequisite knowledge. The integrated AI website supported this process by distributing tiered content, ensuring that each student accessed learning materials appropriate to their readiness level.

Population, sample, and research subjects

The study included all eighth-grade students at one of state secondary schools at Semarang City, Central Java in 2024/2025 academic Year. The sample had two groups: experimental and control. The experimental group experienced differentiated CBL-STEM Context learning integrated by AI-Website, while the control group received problem-based instruction via worksheets (LKPD) as conventional learning. Six students from the experimental group, selected purposively, represented the highest and lowest AQ scores in each category: Quitter, Camper, and Climber as research subjects in the qualitative phase.

Data collection techniques

In the quantitative phase, the effectiveness of the learning model was measured using test instruments in a pre-post group design to assess students' critical thinking skills before and after learning. The Adversity Quotient of students in the experimental group was then assessed using an AQ questionnaire. The results were used to analyze the influence of AQ on critical thinking skills and to classify AQ categories. In the qualitative phase, students in the experimental group were

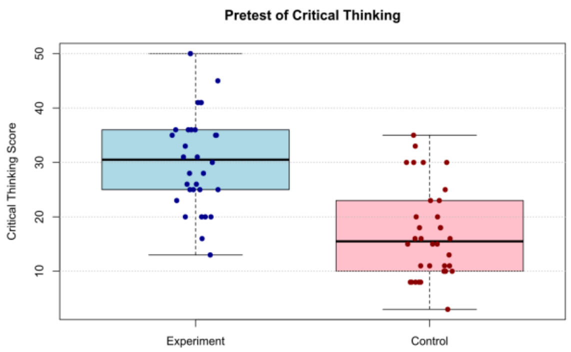


Figure 1. (a) Distribution of critical thinking in each group before treatment

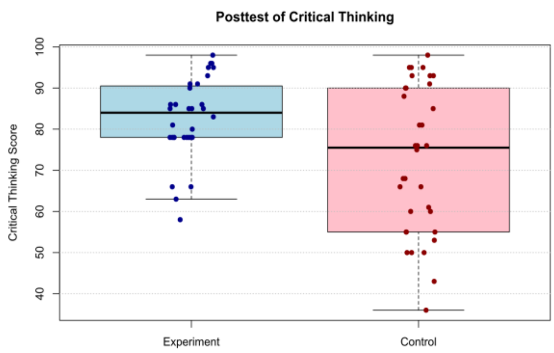


Figure 1. (b) Distribution of critical thinking in each group after treatment

categorized according to AQ grouping criteria proposed by Stoltz (1997) as presented in Table 2. Each research subject was asked to verbally explain the solution to one of the posttest problems to describe the critical thinking skills characteristic of each Adversity Quotient category. The reliability of research instruments was examined before quantitative analysis. The critical thinking test had excellent internal consistency, with Cronbach's Alpha of α = 0.9224. The Adversity Quotient questionnaire showed acceptable reliability, with Cronbach's Alpha of α = 0.7261. These results confirmed that both instruments were suitable for use in this study.

Data analysis techniques

Effectiveness was analysed in the quantitative phase using hypothesis testing. Analysis used R software to calculate p-values, which were compared to a significance level of α = .05. This determined if the hypotheses were supported. Hypotheses were formulated using statistical methods in R (Field et al., 2012). The analysis methods for each quantitative analysis focus are presented in Table 3.

The influence of Adversity Quotient was measured with linear regression between AQ scores and posttest results from the experimental group. AQ affected critical thinking skills if the regression analysis showed a significant effect. The R^2 value described the effect's size.

In the qualitative phase, interviews were held with research subjects to gain insights into their critical thinking skills in each AQ category. Each subject's achievement of indicators was assessed by matching posttest results with interview transcripts. The fulfilment of indicators for each AQ category was analysed to conclude. This gave a detailed description of critical thinking skills across the different AQ categories.

FINDINGS

Effectiveness of learning using differentiated challenge-based STEM context learning (CBL-STEM Context) integrated AI-website

At the end of the quantitative phase, a mapping exercise was conducted to identify the distribution of students' critical thinking skills, both before and after the treatment. This score distribution includes the range of values, the median, and the spread of data for both the experimental and control groups. Based on Figure 1(a), the distribution of students' critical thinking skills in both groups is relatively low and comparable. After the intervention, Figure 1(b). shows a shift in the score distribution toward higher values and more variance. Although the distribution mapping clearly indicates a difference in the experimental group's critical thinking skills between the pretest and posttest results, with outcomes tending to be higher than those of the control group, statistical testing must still be conducted to provide formal statistical evidence.

In the quantitative analysis phase, the results include the experimental group's mean posttest score achieving the Minimum Competency Criteria (KKTP), the proportion of students in the experimental group achieving KKTP exceeding 70%, a significant improvement in students' critical thinking test results, a higher mean posttest score in the experimental group compared to the control group, and a higher proportion of mastery in the experimental group than in the control group.

Table 4

Quantitative hypothesis testing results

Analysis Focus	Aspect	Description
1	Statistical Hypothesis	H_0: The mean posttest score of the experimental group is not higher than KKTP (75). H_1: The mean posttest score of the experimental group is higher than KKTP.
	Test Result and Conclusion	One-sample t-test indicated that the experimental group's mean posttest score of 82.91 compared to the KKTP yielded t = 4.5545 with 0003834 $< \alpha =$ .05. Therefore, H_0 is rejected.
	Conclusion	The mean post-test score of the experimental group exceeds the KKTP.
2	Hypothesis	H_0: The proportion of the experimental group achieving KKTP is not higher than 70% H_1: The proportion of the experimental group achieving KKTP is higher than 70%.
	Test Result	The non-parametric binomial test indicated that 86.67% of students achieved KKTP, with $p = 0.00915 < \alpha = 0.05$, leading to rejection of H_0.
	Conclusion	The proportion of students achieving KKTP exceeds 70%.
3	Hypothesis	H_0: The mean posttest score of the experimental group is not higher than the mean pretest score. H_1: The mean posttest score is higher than the mean pretest score. The increase is further described using N-Gain.
	Test Result	Paired t-test showed t = 27.954 and$p = .000000000000002 < \alpha = .05$, with a mean increase of 51.93 points. The mean N-Gain of the experimental group was 0.756.
	Conclusion	A significant increase in critical thinking test results was observed, categorized as high.
4	Hypothesis	H_0: The mean posttest score of the experimental group is not higher than the mean posttest score of the control group. H_1: The mean posttest score of the experimental group is higher than that of the control group.
	Test Result	Independent sample, less than alpha equals .05. So H_0 is rejected.
	Conclusion	The experimental group's mean post-test score is higher than the control groups.
5	Hypothesis	H_0: The mean N-Gain of the experimental group is not higher than that of the control group. H_1: The mean N-Gain of the experimental group is higher than that of the control group.
	Test Result	Mann-Whitney test yielded p = 0.003295, leading to rejection of H_0.
	Conclusion	The mean N-Gain of the experimental group is higher than that of the control group.

Therefore, the differentiated CBL-STEM Context integrated AI-Website is considered effective at enhancing students' critical thinking skills. Detailed hypothesis testing results are presented in Table 4.

Influence of adversity quotient on students' critical thinking skills

The study used linear regression to analyze how Adversity Quotient (AQ) affects critical thinking skills, finding only an 8.4% impact, considered very low, with the regression equation $Y = 0.06 + 75.41$. This shows AQ has minimal influence on critical thinking in the Challenge-Based STEM Context with AI-Website. Consequently, the AQ category further examined students' achievement in critical thinking. The illustration of influence is shown in Figure 2, and the details of the results are presented in Table 5.

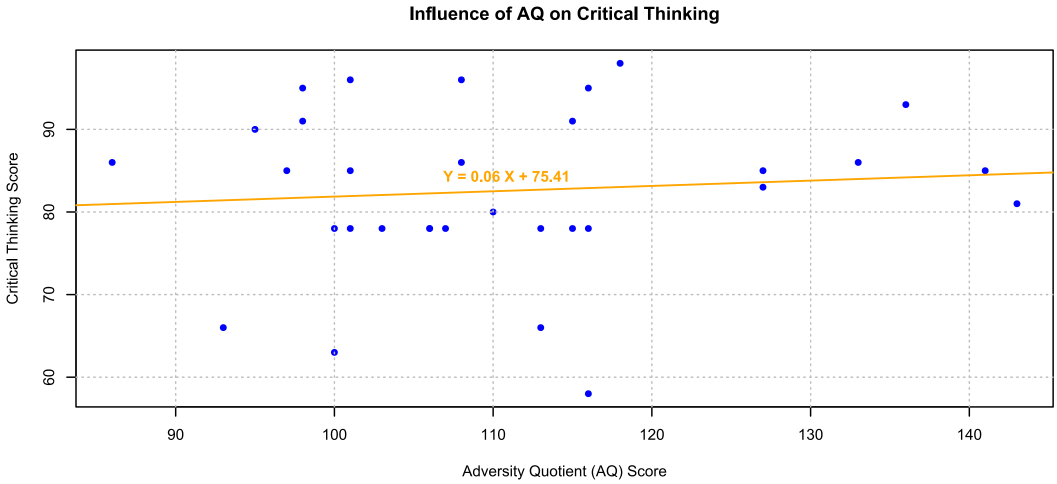


Figure 2. Linear regression graph

Table 5
Linear regression analysis of AQ influence

Aspect	Description
Hypothesis	H_0: There is no significant effect of AQ on critical thinking skills ($\beta = 0$). H_1: There is a significant effect of AQ on critical thinking skills ($\beta > 0$).
Test Result	Linear regression analysis shows a regression coefficient value of 0.204 with a p-value = 0.046, indicating that the AQ (Adversity Quotient) variable affects the Posttest Results of 8.4%.

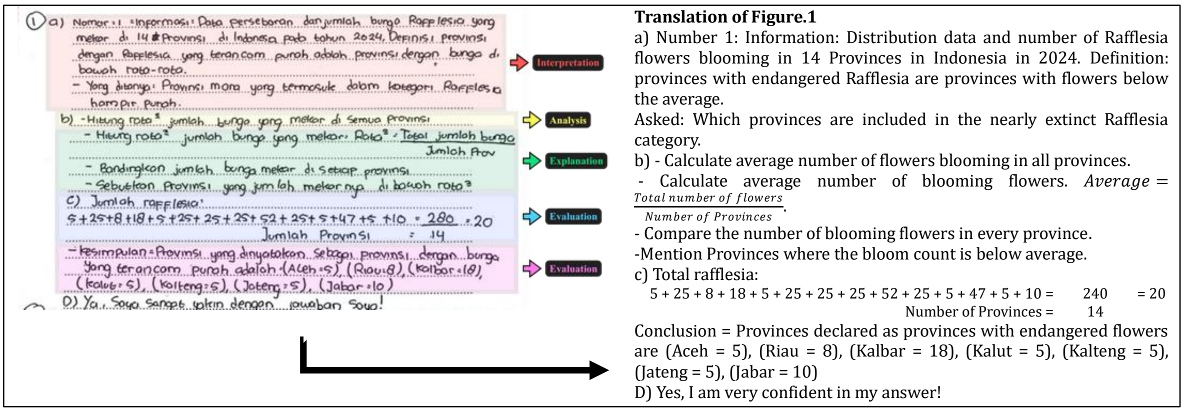
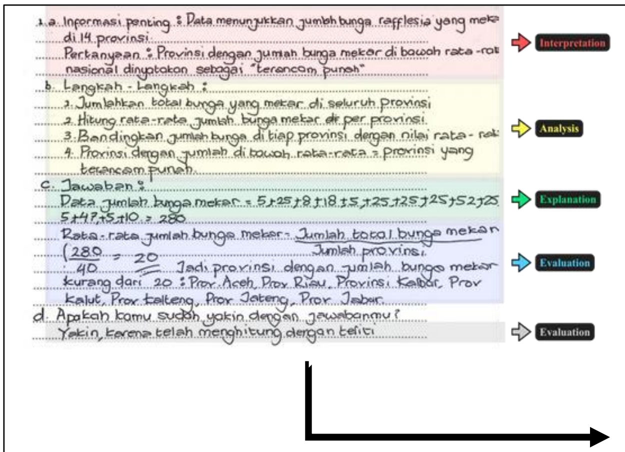


Figure 3. Student answers Cl. 1

Critical thinking skills based on adversity quotient in mathematics learning using a differentiated CBL-STEM context integrated AI-website

Analysis of subject CL. 1

Six research subjects were selected based on AQ results, with two students per category. Student Cl. 1 from the Climber category had the highest CO2RE score of 143, scoring well in control, range, endurance, and origin, while ownership was moderate. Based on the written test in Figure 3 and subsequent validation, Cl. 1 demonstrated fulfillment of nearly all critical thinking skill indicators. In the interpretation indicator, the written artifacts on Cl. 1's answer sheet in Figure 3 display a precise breakdown of the distribution data of *Rafflesia* flowers across 14 provinces and systematically lay out the problem's criteria. During the interview, Cl. 1 confirmed this deep



Translation of Figure.2
a) Important information: Data shows the number of rafflesia flowers blooming in 14 provinces.
Question: Provinces with the number of blooms below the national average are declared as "endangered".
Asked: Which provinces are included in the nearly extinct Rafflesia category.
b) Steps:
1. Sum up total flowers blooming in all provinces
2. Calculate average number of flowers blooming per province
3. Compare number of flowers in each province with the average value
4. Province with amount below average = province that is endangered

c) Answer:
Data of blooming flower count $= 5 + 25 + 8 + 18 + 5 + 25 + 25 + 25 + 52 + 25 + 5 + 47 + 5 + 10 = 280$.
Average number of blooming flowers $= \frac{\textit{Total number of blooming flowers}}{\textit{Number of provinces}} = \left(\frac{280}{14}\right) = 20$.
So, provinces with number of blooming flowers less than 20: Prov Aceh, Prov Riau, Province Kalbar, Prov Kalut, Prov Kalteng, Prov Jateng, Prov Jabar.
D) Are you confident in your answer?
Confident, because I have calculated carefully.

Figure 4. Student answers Cl. 2

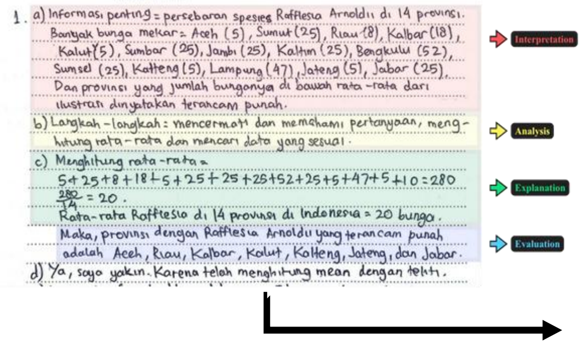
structural understanding of the problem by stating, *"I know it is about provinces where the number of blooming flowers is below the average."*

For the analysis indicator, the operational mathematical steps written down on Cl. 1's answer sheet in Figure 3 show a flawless execution of statistical reasoning, where the student summed all provincial counts to 280 and divided the total by 14 to locate the exact average value of 20. In terms of explanation and evaluation indicators, Cl. 1's written paper in Figure 3 shows structured steps justifying the mean concept as the baseline threshold to distinguish threatened regions. Verbally, Cl. 1 supported these procedural steps by stating, *"I added all the blooming flowers to get 280, then divided by 14, so the average is 20. Provinces with fewer than 20 blooming flowers are considered endangered."* For the inference indicator, Cl. 1's written conclusion in Figure 3 successfully provides the correct complete list of endangered provinces: Aceh, Riau, West Kalimantan, North Kalimantan, Central Kalimantan, Central Java, and West Java. However, a visual inspection of Cl. 1's written answers reveals a total absence of review marks or alternative calculation checks, which was validated when Cl. 1 stated, *"However, I did not get the chance to recheck it."* This omission confirms that the student failed the self-regulation indicator. Reflecting the high resilience of a high-AQ Climber, Cl. 1 expressed a strong affinity for the complex pacing of the platform, explaining, *"I liked the challenge. The questions got tougher as we went on, unlike school, where everything feels too easy."* Consequently, subject CL. 1 successfully fulfilled the indicators of interpretation, analysis, explanation, evaluation, and inference, whereas the indicator of self-regulation remained unachieved.

Analysis of subject CL. 2

Cl. 2, a student from the Climber category with the lowest category CO2RE score of 136, exhibited good control, range, and endurance, moderate ownership, and low origin. Based on the written test in Figure 4 and verbal responses, Cl. 2 met most critical thinking skills, including interpretation, analysis, explanation, inference, and self-regulation. On the written answer sheet shown in Figure 4, Cl. 2 successfully fulfilled the interpretation indicator by correctly noting down the core framework of the *Rafflesia* distribution problem. When asked during the interview, Cl. 2 reinforced this by stating, *"It is about the number of Rafflesia flowers in several provinces, and also the total number of endangered ones."* For the analysis indicator, Cl. 2's written calculations in Figure 4 clearly display the correct process of aggregating the total count to 280 and dividing it by 14 to determine the average of 20.

However, Cl. 2 failed the evaluation indicator; the written work in Figure 4 shows simplistic, ill-structured reasoning regarding why certain provinces are categorized as endangered. When questioned about this written process, Cl. 2 provided an illogical explanation, stating, *"Because the majority value is 20. So, if it does not reach that minimum, it means it is endangered."* For the inference



Translation of Figure.3

a) Important information = distribution of Rafflesia Arnoldii species in 14 provinces. Number of flowers blooming = Aceh (5), N. Sumatra (25), Riau (8), W. Kalimantan (18), N. Kalimantan (5), W. Sumatra (25), Jambi (25), E. Kalimantan (25), Bengkulu (52), S. Sumatra (25), C. Kalimantan (5), Lampung (47), C. Java (5), W. Java (25). And provinces where the flower count is below the average from the illustration are declared endangered.

b) Steps: observe and understand the question, calculate the average and find the appropriate data.

c) Calculating average:

$$5+25+8+18+5+25+25+25+52+25+5+47+5+10=280$$

$$\frac{280}{14}=20.$$

Average of Rafflesia in 14 provinces in Indonesia = 20.

Therefore, provinces with Rafflesia Arnoldii that are endangered are Aceh, Riau, Kalbar, Kalut, Kalteng, Jateng, and Jabar.

D) Yes, I am confident. Because, I have calculated the mean carefully.

Figure 5. Student answers Ca. 1

indicator, while Cl. 2's written resolution in Figure 4 attempted to map out the target regions, the student completely omitted West Kalimantan from the verbal list during interview validation, stating that the endangered provinces were *"Aceh, Riau, North Kalimantan, Central Kalimantan, Central Java, and West Java."* In terms of self-regulation, Cl. 2's answer sheet in Figure 4 shows visible signs of review and double-checking, which was confirmed when the student stated, *"I am confident because I have reviewed my answer."* Driven by the interactive design of the platform, Cl. 2 noted, *"I liked it because the visuals were interesting, like a game where you fight an AI. Also, the questions were doable for me."* In summary, subject CL. 2 satisfied the indicators of interpretation, analysis, explanation, inference, and self-regulation, but failed to demonstrate proficiency in the evaluation indicator.

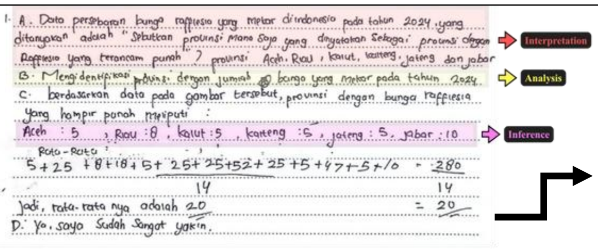
Analysis of subject Ca. 1

Subject Ca. 1 represented the Camper category with the highest CO2RE score of 133, displaying good control, range, and endurance, moderate ownership, and low origin. Based on the test in Figure 5 and the interviews, Ca. 1 demonstrated key baseline critical thinking skills. On the written answer sheet in Figure 5, Ca. 1 successfully satisfied the interpretation indicator by identifying the fundamental parameters of the *Rafflesia arnoldii* provincial count in 2024. During the interview session, Ca. 1 explained this setup, noting, *"So, the problem gives data on Rafflesia flower distribution in the provinces. To solve it, I just used the average."* For the analysis indicator, Ca. 1's written calculations in Figure 5 show a successful attempt at summing the data points to 280 and dividing by 14 to locate the baseline average of 20.

However, Ca. 1 underperformed or failed across all higher-order indicators, as shown by the structural flaws on the answer sheet. In the explanation aspect, Ca. 1's written response provides a superficial procedural summary without deeper mathematical arguments, stating in the interview, *"I added all the numbers up and then divided by 14. Any province with a count below the average of 20, I considered endangered. For example, like Aceh and Riau."* Ca. 1 completely failed the evaluation indicator; the work in Figure 5 contains highly illogical reasoning, explicitly arguing that West Kalimantan was threatened because its value was "close to the average". This flawed evaluation caused inconsistent results in the inference indicator, as Ca. 1 mistakenly included West Kalimantan on the final written list despite it not matching the mathematical criteria. Finally, Ca. 1 failed the self-regulation indicator, leaving the work completely unchecked and admitting, *"I included that one too because its number is close to the average. However, I have not actually double-checked it."* Characteristically acting like a Camper who seeks comfortable connections, Ca. 1 preferred science-framed tasks over mathematics, stating, *"I liked it because the lesson used Science questions. I actually prefer Science over Math."*

Analysis of subject Ca. 2

Ca. 2 was a Camper student with the lowest category CO2RE score of 95, showing good control and endurance, moderate range and origin, and low ownership. Based on the test in Figure 6 and verbal data, Ca. 2 met the fundamental critical thinking parameters. On the written answer sheet shown in Figure 6, Ca. 2 successfully met the interpretation indicator by recording the total number of flowers across the 14 provinces and isolating the primary goal. In the interview, Ca. 2 confirmed



Translation of Figure.4

a) Distribution data of rafflesia flowers blooming in Indonesia in 2024. what is asked is "Mention which provinces are declared as provinces with Endangered Rafflesia?" provinces Aceh, Riau, Kalut, Kalteng, Jateng and Jabar.

b) Identifying provinces with the number of flowers blooming in 2024.

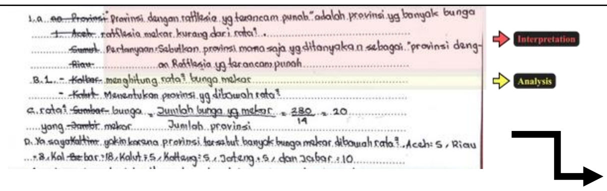
c) Based on data in the image, provinces with rafflesia flowers that are nearly extinct include: Aceh: 5, Riau: 8, Kalut: 5, Kalteng: 5, Jateng: 5, Jabar: 10:

$$5 + 25 + 8 + 18 + 5 + 25 + 25 + 25 + 52 + 25 + 5 + 47 + 5 + 10 = \frac{280}{14}$$

So, the average is 20.

D) Yes. I am already very confident.

Figure 6. Student answers Ca. 2



Translation of Figure.5

a) "Provinces with endangered Rafflesia" are provinces where the number of blooming Rafflesia flowers is less than the average. Question: Name which provinces are referred to as "provinces with endangered Rafflesia.

b) - Calculating the average of blooming flowers.

- Determining the provinces that are below the average.

c) Average blooming flowers: $\frac{Total\ number\ of\ blooming\ flowers}{Number\ of\ provinces} = \frac{280}{14} = 20$

$$5 + 25 + 8 + 18 + 5 + 25 + 25 + 25 + 52 + 25 + 5 + 47 + 5 + 10 = \frac{280}{14}$$

D) Yes, I am certain because those provinces have blooming flower counts below the average, Aceh: 5, Riau: 8, Kalut: 5, Kalteng: 5, Jateng: 8, and Jabar: 10.

Figure 7. Student answers Qu. 1

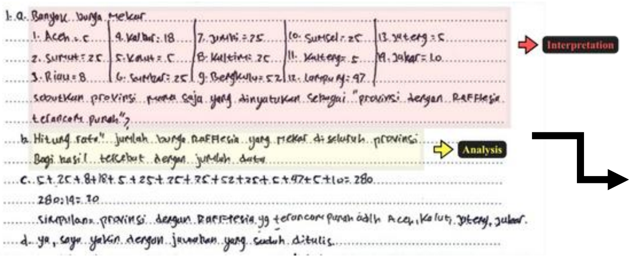
this focus: *"The information is the total number of flowers in 14 provinces, and we are asked to find the average."* For the analysis indicator, Ca. 2's written work in Figure 6 accurately details the computation steps $\sum Data = 280$, divided by 14, to reach the mean value of 20.

However, Ca. 2's explanation indicator was only partially met because the narrative written on the paper was extremely basic and lacked detailed justification, matching the short verbal statement: *"The result is 20, and the criteria are provinces with fewer than 20 flowers."* Ca. 2 failed the evaluation indicator because the decision-making process on the answer sheet was applied mechanically to the "below 20" rule without independent validation of outliers. Despite this, Ca. 2 satisfied the inference indicator by writing down and stating the exact list of endangered provinces: *"The provinces are Aceh, Riau, West Kalimantan, North Kalimantan, Central Kalimantan, Central Java, and West Java. I am sure."* For the self-regulation indicator, although Ca. 2 expressed confidence, the written sheet in Figure 6 showed that the student did not critically reflect on errors or evaluate structural alternatives. Interestingly, Ca. 2 adapted well to the step-by-step guidance of the digital platform, noting, *"I liked that whenever I made a mistake, the website pointed it out and showed me exactly where I went wrong. It also guided me through it step-by-step, even though it took longer."* Ultimately, subject Ca. 2 demonstrated mastery in the interpretation, analysis, and inference indicators, whereas explanation, evaluation, and self-regulation were not fully optimized.

Analysis of subject Qu. 1

Subject Qu. 1 from the Quitter category had the highest category CO2RE score of 93, with good control, range, and endurance, while origin and ownership were low. Based on the written test in Figure 7 and the interview results, Qu. 1 demonstrated compliance only at the foundational tiers of critical thinking. On the answer sheet in Figure 7, Qu. 1 met the interpretation indicator by transcribing the raw data points of the 14 provinces. This matched the student's verbal summary: *"I was told to find the average and figure out which provinces have endangered plants, based on the data of Rafflesia numbers in Indonesia."* For the analysis indicator, Qu. 1 successfully established the link between finding the numerical average of 20 and selecting the targeted provinces on paper.

However, Qu. 1 fell short across all higher-order critical thinking indicators, as evidenced by significant errors on the written paper. In explanation, the written text lacked mathematical depth, relying on a superficial rule: *"Basically, any province with a count under 20 is endangered."* In evaluation and inference, Qu. 1's written sheet in Figure 7 shows visible confusion and unverified



Translation of Figure.6
a) Number of Blooming Flowers.

1. Aceh: 5	5. Kalut: 5	9. Bengkulu: 52	13. Jateng: 5
2. Sumut: 25	6. Sumur: 25	10. Sumsel: 25	14. Jabar: 10
3. Riau: 8	7. Jambi: 25	11. Kalteng: 5	
4. Kalbar: 18	8. Kaltim: 25	12: Lampung: 47	

b) Calculate the average number of Rafflesia flowers blooming in a provinces. Divide the result by the number of data points.
c) 5 + 25 + 8 + 18 + 5 + 25 + 25 + 25 + 52 + 25 + 5 + 47 + 5 + 10 = 280

$$\frac{280}{14} = 20$$

Conclusion: The provinces with endangered Rafflesia are Aceh, Kalu Jateng, Jabar.
D) Yes, I am certain with the answer that has been written.

Figure 8. Student answers Qu. 2

final values; the student wrote down an incorrect final regional list, which was mirrored in the interview text: *"The final list is North Kalimantan, Aceh, Riau, Central Kalimantan, and Central Java. I am pretty sure, but I have not actually re-checked the calculations."* By failing to notice that East Kalimantan (25) was incorrectly included and Riau (8) was completely ignored, Qu. 1 failed both the inference and evaluation indicators. This unverified step also demonstrates a failure in the self-regulation indicator. Due to a low tolerance for learning obstacles, Qu. 1 showed an explicit reliance on direct intervention, explaining, *"I liked it when you corrected my mistakes and explained the things I forgot."* Hence, subject Qu. 1 successfully met the interpretation and analysis indicators but fell short of fulfilling the explanation, evaluation, inference, and self-regulation benchmarks.

Analysis of subject Qu. 2

Qu. 2, a student from the Quitter category with the lowest category CO2RE score of 86, possessed good control, moderate range and endurance, alongside low origin and ownership. Based on the written sheet in Figure 8 and corresponding interviews, Qu. 2 fulfilled only the most basic critical thinking steps. On the written paper in Figure 8, Qu. 2 completed the interpretation indicator by identifying the baseline distribution data and locating the primary instruction to find regions at risk of extinction. During the interview, Qu. 2 summarized this setup briefly: *"It is about the Rafflesia flower data in Indonesia. I am solving it using the average."* For the analysis indicator, the operational calculation steps written on Qu. 2's sheet show a correct execution of the mean formula, adding the values to 280 and dividing by 14 to obtain 20.

However, Qu. 2 completely underperformed or failed in the remaining higher-level indicators. For the explanation aspect, Qu. 2's written work lacked analytical argument, providing only a vague rule: *"Maybe the ones below 20 are the endangered ones."* In the evaluation indicator, Qu. 2's answer sheet in Figure 8 shows clear signs of careless data management; the student initially wrote down East Kalimantan (25) as an endangered province. This error required external intervention to fix, meaning the student failed the independent evaluation parameter. This flawed process compromised the inference indicator as well, leaving the final written list inaccurate until outside corrections were applied. For self-regulation, although Qu. 2 claimed, *"Yes, I am sure, and I have already checked it,"* the persistent errors on the paper prove that genuine reflective checking was missing. Showing a preference typical of a low-AQ student who is easily overwhelmed, Qu. 2 responded positively only when tasks were structured with manageable difficulty, stating, *"Personally, I liked it because the questions were pretty easy. At first, I thought they were going to be really hard."*

In the qualitative phase, interviews showed that students with different AQ categories (Climber, Camper, and Quitter) varied in their ability to fulfill critical thinking skill indicators. Based on Table 6, students across AQ categories varied in meeting critical thinking indicators despite similar average scores. The Climber category excelled in Interpretation, Analysis, and Inference, with Cl. 1 needing more Self-Regulation and Cl. 2 improving evaluation skills. The Camper category, with the largest number of students, showed notable differences in problem-solving. Qu. 2 understood basic info and applied analysis, but during interviews, struggled with Explanation and Self-Regulation, showing limited reasoning and reflection. The Quitter group scored low in Evaluation, Explanation, Inference, and Self-Regulation. The low self-regulation suggests metacognitive skills are

Table 6
Critical thinking skills indicator achievement results

Indicators	Students					
	Cl. 1	Cl. 2	Ca. 1	Ca. 2	Qu. 1	Qu. 2
Interpretation	✓	✓	✓	✓	✓	✓
Analysis	✓	✓	✓	✓	✓	✓
Explanation	✓	✓	✓			
Evaluation	✓		✓			
Inference	✓	✓		✓		
Self-Regulation		✓				

not automatically developed through differentiated CBL-STEM Context with AI. Despite strong analysis, reflection, and self-monitoring are limited. Explicit scaffolding like reflection prompts and AI feedback are needed to enhance self-regulation, though Qu. 2 still met Interpretation and Analysis indicators follows.

Interview responses show that different AQ categories favor certain learning elements for improving critical thinking. While AQ's influence in the CBL-STEM Context model is small, it still helps student development. Instructional elements also provide substantial support, with improvements stemming from both AQ and these components, though instruction has a stronger impact. Climbers preferred differentiated instruction and AI-Website support for higher-level challenges and practice, aiding exploration and problem-solving. Campers favored STEM elements and differentiated learning to connect new concepts and foster understanding. Quitters valued structured problems, clear sequences, and opportunities to recall prior knowledge, which increased their confidence and critical thinking. These results suggest that, although AQ's role is modest, instructional scaffolding significantly enhances critical thinking skills.

DISSCUSION

This study shows that differentiated CBL-STEM Context learning integrated with AI-Website effectively enhances students' critical thinking skills. Through the CBL model, students are supported in analyzing and evaluating contextual problems both independently and collaboratively. The statistical results strengthen this conclusion, with the experimental group achieving an average posttest score of 82.91, a 75.6% increase in critical thinking skills, and a learning completion rate of 86.67%. Comparative tests further confirmed the superiority of the experimental group over the control group. These findings align with previous studies showing that AI-Website and STEM-Context learning models systematically promote higher-order thinking skills, including critical thinking. This result is consistent with Zhu et al. (2021), who demonstrated through a randomized experiment that CBL-STEM Context learning significantly enhances students' higher-order thinking skills. These findings also align with Zabian (2025), who found that AI-Website learning systems can improve academic mastery through adaptive, structured learning. The architectural integration of such intelligent web-based tutoring models systematically optimizes individual student performance by deploying advanced neural algorithms to predict learning behavior and adjust content pathways accordingly (Gomede et al., 2021). In line with this, Panggabean et al. (2025) demonstrated that a validated Canva-IBL-STEM model significantly enhances higher-order thinking skills, particularly in analytical and problem-solving dimensions. This empirical correlation highlights that the strategic implementation of structured digital learning systems serves as an essential pathway to systematically accelerate and elevate students' higher-order cognitive performances (Mat et al., 2024). These findings support the argument that integrating STEM with digital learning platforms can systematically foster students' higher-level cognitive processes, including critical thinking. Thus, the learning success in this study is consistent with recent empirical evidence on the effectiveness of collaboration among CBL-STEM Context, AI-Website, and differentiated learning in developing students' critical thinking skills. By synthesizing these three educational innovations, the blended environment successfully orchestrates a comprehensive learning ecosystem where student autonomy and cognitive growth are nurtured concurrently (Chiu, 2021).

Interview results revealed differences in the mastery of critical thinking indicators across AQ categories. All groups achieved the basic indicators of interpretation and analysis, but variations appeared in explanation, evaluation, inference, and self-regulation. Climber students generally demonstrated stronger mastery of these higher-level indicators than Campers and Quitters. Previous studies also support this pattern, indicating that students with higher AQ tend to solve problems more accurately and use more logical reasoning than those with lower AQ. This pattern is also supported by Zhao and Sang (2023), who found that AQ contributes to cognitive performance, but its influence remains strongly shaped by the surrounding learning conditions. Which indicates that systematic reviews show that the contribution of AQ to critical thinking skills is often small and depends on other variables, such as learning strategies and environmental support. Other studies also show that although students with high AQ tend to demonstrate better learning performance, the effect of AQ does not stand alone and is still shaped by various learning conditions (Anggraini & Mahmudi, 2021). Thus, differentiated challenge-based STEM Context learning integrated AI-Website can bridge the AQ gap, enabling all students to achieve relatively equal critical thinking skills.

Variations in N-gain scores were also influenced by learning preferences across the three AQ categories: Climbers, Campers, and Quitters. Although AQ's impact on critical thinking is relatively small, it still affects how students respond to instructional support. The use of AI-Website and differentiated CBL-STEM Context learning provided structured scaffolding that addressed each group's needs. Climbers favored AI integration and differentiated tasks because they offer advanced challenges and opportunities for exploration. Campers preferred the gradual structure of STEM Context learning combined with differentiation, which helped them connect ideas more effectively. Quitters depended on structured, differentiated learning that offers step-by-step guidance and reinforces prerequisite knowledge. This AI-Website scaffolding helped both Campers and Quitters exceed expectations in critical-thinking indicators based on their AQ profiles. A similar tendency was reported by Pramuditya et al. (2022), who showed that structured support within an open-ended learning environment significantly improves students' mathematical problem-solving abilities. According to the qualitative study by Putri and Alyani (2023), Participants with the climber type can solve problems more accurately. In contrast, those with the quitter type tend to meet only the interpretation indicator. Students with high AQ were better able to reason and provide logical-mathematical explanations than students with low AQ when solving non-routine problems. This operational difference reflects a core pattern where resilient learners instinctively deploy more effective self-regulated metacognitive strategies when untangling non-routine tasks (Veenman, 2021). Overall, the findings of this study indicate that the higher a student's AQ, the more complete the indicators of mathematical critical thinking they can achieve in the problem-solving process. However, the tactical integration of digital technology helps reconstruct how students approach challenging tasks, allowing vulnerable learners to effectively emulate advanced analytical pathways (Attard & Holmes, 2022). The use of data-driven predictive frameworks, as highlighted by He et al. (2025), further underscores the capacity of adaptive technologies to optimise learning pathways in mathematics education.

The results of this study show that differentiated CBL-STEM Context learning integrated with an AI-Website effectively improves students' critical thinking skills while also reducing the limiting effect of low AQ on these outcomes. This addresses the research gap, as prior studies didn't combine AI-Website, CBL-STEM Context, and differentiated learning in a single framework. AI-Website learning boosts students' critical thinking and interacts positively with AQ by offering adaptive support beyond traditional methods. Qualitative data also reveal that students across all AQ categories, Climbers, Campers, and Quitters, reached various critical thinking levels. Even students with lower AQ scores mastered indicators through scaffolding provided by differentiated tasks, challenges, and AI pathways. These findings align with Nasir et al. (2022), who reported that STEM guided inquiry improves students' conceptual understanding and scientific explanation skills across varying levels of ability. This instructional alignment demonstrates that when digital scaffolding is paired with variable task structures, it effectively broadens cognitive access, allowing less resilient or lower-achieving groups to successfully engage with advanced problem-solving phases (Setyaningrum et al., 2024). These outcomes also surpass those typically seen in traditional classrooms, where students with low AQ often meet only basic critical-thinking standards. Emphasizes that although AQ influences critical thinking, its impact is relatively small and heavily dependent on the instructional strategies used. Therefore, models that offer adaptive, differentiated support, like here, help close performance gaps among diverse AQ profiles. This research addresses the unexamined integration gap and shows that AI-supported, differentiated CBL-STEM Context learning can promote fairer development of critical thinking skills across all AQ categories.

Overall, differentiated CBL-STEM Context learning integrated with an AI-Website proved effective in improving critical thinking skills and in reaching all AQ categories. Although the influence of AQ was relatively small, this shows that differentiated learning models can accommodate learners with diverse backgrounds and initial abilities. These findings reinforce the conclusion that integrating AI into differentiated CBL-STEM Context learning is a relevant innovation for comprehensively improving critical thinking skills.

CONCLUSIONS

This study concludes that the integration of differentiated CBL-STEM Context integrated with AI-Website instruction is effective in improving students' critical thinking skills. This effectiveness is demonstrated by significantly higher post-test scores, stronger N-Gain results, and better mastery of KKTP in the experimental group compared to the control group. Furthermore, findings indicate that the Adversity Quotient (AQ) has an impact on learning at the lower level, suggesting that other factors influence the development of critical thinking skills among students. Interviews revealed distinct patterns in the fulfillment of critical thinking indicators. Students in the higher AQ category tended to consistently fulfill critical thinking indicators, while students with lower AQ initially struggled to meet some indicators. All subjects tend to be able to consistently perform well on interpretation and analysis indicators, but differences appear in indicators such as evaluation and inference. This was found to be due to differences in learning preferences, where students in the Climber group were better able to adapt to the learning process because it aligned with the AI-Website and the gradually increasing level of difficulty, while the Camper group preferred learning that linked the material to everyday life or other topics through CBL-STEM Context; whereas the Quiter group itself tends to rely more on scaffolding through differentiated learning, because the learning still focuses on improving critical thinking skills based on their initial abilities, causing the Quiter group to have some difficulty adapting to the learning process. Therefore, in general, differentiated CBL-STEM Context learning integrated with an AI-Website is effective in enhancing students' critical thinking skills.

Research focused on improving critical thinking skills in general found that subjects in the low AQ category did not meet as many indicators as those in other categories. Therefore, future research is expected to integrate differentiated learning by AQ categories. The small sample size is a limitation of this study; therefore, it is hoped that future research will be conducted on other populations to enrich existing findings by integrating differentiated CBL-STEM context-based learning with an AI-website based on students' AQ.

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AUTHORS' DECLARATION

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