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Determination of Scientific Argumentation Skills of Biology (Contribution to Digital Literacy and Critical Thinking Skills of High School Students)

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Abstract

This study aims to examine the relationship between digital literacy and critical thinking skills with high school students' scientific argumentation abilities. The research employed a quantitative correlational design with purposive sampling. Sampling was based on the Kruskal–Wallis equivalence test, which showed unequal population groups; therefore, further analysis identified classes with comparable learning outcomes. Data were collected through tests and non-test instruments, including questionnaires and interviews, to measure digital literacy, critical thinking, and scientific argumentation. Multiple linear regression, t-tests, F-tests, coefficients of determination, and correlation analyses were used to analyze the data. The findings revealed that (1) digital literacy has a significant negative correlation with scientific argumentation skills ($p = 0.001 < 0.05$); (2) critical thinking skills have a positive and significant correlation ($p = 0.001 < 0.05$); and (3) both variables jointly contribute 31.8% to scientific argumentation abilities. These results indicate that technical digital proficiency alone does not strengthen students' argumentation unless accompanied by strong evaluative skills, while critical thinking consistently enhances their ability to construct evidence-based arguments. The study highlights the need for integrating critical digital literacy and explicit critical thinking instruction into science learning to foster students' capacity to formulate coherent, logical, and evidence-driven scientific arguments.

Keywords: Scientific Argumentation Skills, Critical Thinking Skills, Digital Literacy

Determinasi Keterampilan Argumentasi Ilmiah Biologi (Kontribusi Literasi Digital dan Keterampilan Berpikir Kritis Siswa SMA)

Abstrak

Penelitian ini bertujuan untuk mengkaji hubungan antara literasi digital dan keterampilan berpikir kritis dengan kemampuan argumentasi ilmiah siswa SMA. Penelitian ini menggunakan desain kuantitatif korelasional dengan teknik purposive sampling. Pengambilan sampel didasarkan pada uji kesetaraan Kruskal–Wallis

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yang menunjukkan ketidakseimbangan antar kelompok populasi; oleh karena itu, analisis lanjutan dilakukan untuk mengidentifikasi kelas dengan hasil belajar yang sebanding. Data dikumpulkan melalui tes dan instrumen non-tes, termasuk angket dan wawancara, untuk mengukur literasi digital, berpikir kritis, dan argumentasi ilmiah. Analisis data menggunakan regresi linier berganda, uji t, uji F, koefisien determinasi, dan analisis korelasi. Temuan penelitian menunjukkan bahwa (1) literasi digital memiliki korelasi negatif yang signifikan dengan kemampuan argumentasi ilmiah ($p = 0{,}001 < 0{,}05$); (2) keterampilan berpikir kritis memiliki korelasi positif dan signifikan ($p = 0{,}001 < 0{,}05$); dan (3) kedua variabel tersebut secara bersama-sama berkontribusi sebesar 31,8
% terhadap kemampuan argumentasi ilmiah. Hasil ini menunjukkan bahwa kecakapan digital teknis saja tidak meningkatkan kemampuan argumentasi siswa tanpa disertai keterampilan evaluatif yang kuat, sedangkan berpikir kritis secara konsisten meningkatkan kemampuan mereka dalam menyusun argumen berbasis bukti. Penelitian ini menekankan perlunya integrasi literasi digital kritis dan pengajaran berpikir kritis secara eksplisit dalam pembelajaran sains untuk mengembangkan kemampuan siswa dalam merumuskan argumen ilmiah yang koheren, logis, dan berbasis bukti.

Kata kunci: Keterampilan Argumentasi Ilmiah, Keterampilan Berpikir Kritis, Literasi Digital.

INTRODUCTION

The 21st century, marked by rapid technological and information advancement, demands that students master essential skills to thrive in future careers, learning environments, and innovative endeavors. These competencies, often encapsulated as the 4Cs—Communication, Collaboration, Critical Thinking, and Creativity—are foundational for success in a dynamic global landscape (Hamzah et al., 2023). To cultivate these skills, a shift towards student-centered learning is imperative, providing opportunities for students to engage in scientific thinking and develop the attitudes and competencies of scientists (Shofiya & Wulandari, 2018). Within this framework, scientific argumentation emerges as a critical competency. It is the process of constructing and justifying scientific claims with evidence and reasoning, a practice central to the scientific community (Osborne, 2010). Proficiency in argumentation enables students to critically address problems, supported by logical and evidence-based reasoning, thereby deepening their conceptual understanding (P. Dewi et al., 2022).

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Scientific argumentation skills play a critical role in science education, as evidenced by various studies. Recent research reveals that these skills not only vary in level among students and need further development (Fakhriyah & Masfuah, 2021), but can also be significantly improved through innovative learning approaches such as inquiry-based online learning (Hendratmoko et al., 2023) and models like the Revised Argument-Driven Inquiry (rADI) (Songsil et al., 2019). The benefits are extensive, ranging from the development of critical thinking skills and improved academic performance (Faize et al., 2018) to enabling students to construct arguments independently (Naylor et al., 2007). However, key challenges persist, such as a lack of scientific accuracy in student arguments (Dahnuss et al., 2023) and difficulties in providing solid explanations and identifying problem limitations (P. A. W. Putri et al., 2024). Research trends recommend a focus on the relationship between argumentation types and teaching materials (Mulyani et al., 2024), supported by bibliometric analyses that confirm the importance of this field (Rahma et al., 2024). In assessment, machine learning technologies like the Bi-LSTM+Attention model have proven to be accurate and practical tools for evaluating these skills (Tian et al., 2025), reinforcing the importance of the comprehensive integration and measurement of scientific argumentation in curricula.

The state of literacy and critical thinking skills in Indonesia is closely and synergistically linked to students' argumentation skills. Studies show that critical thinking skills are significantly correlated with and form a primary foundation for argumentation skills, even accounting for a large portion of their variance (Karadeniz, 2016). Improvement efforts can be pursued through various approaches, such as integrating digital literacy into learning (Nurhasanah et al., 2025), implementing innovative learning models like Ethno-ECLIPSE (Priyambodo et al., 2023), and applying contextual approaches to writing (Hasani, 2017). The aspect of literacy, particularly critical reading skills, has also been proven to strongly correlate with critical thinking skills across various domains (Cahyani, 2019; Wikanengsih et al., 2020). However, major challenges persist, including a lack of consensus among teachers on the best teaching methods (Kintoko et al., 2024) and a significant decline in skills following the COVID-19 pandemic (Gustine et al., 2024). Therefore, enhancing the

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argumentation skills of Indonesian students is highly dependent on integrated strategies that simultaneously strengthen literacy and critical thinking.

Recent research underscores the significance and challenges of developing argumentation skills. Studies consistently highlight a positive correlation between scientific argumentation and critical thinking, where the ability to construct logical arguments is both a component and an outcome of critical thought (S. S. S. Dewi et al., 2023; Sumarni et al., 2017; Winarti et al., 2021a). The digital era has introduced another crucial variable: digital literacy. Research by (Patty et al., 2024) and (Repi et al., 2024a) suggests that digital literacy is vital for sourcing valid and relevant information, which forms the bedrock of strong scientific arguments. Students with high digital literacy are better equipped to navigate vast online resources, select credible evidence, and communicate their ideas effectively in digital spaces (Kurniawan & Sarah, 2023; Silalahi et al., 2022). While existing literature has explored these relationships individually, contemporary studies are beginning to recognize their interconnected nature in shaping 21st-century learning outcomes.

Despite the established importance of argumentation, critical thinking, and digital literacy, a synthesis of these three elements in a single investigative framework remains underexplored. Many previous studies have examined the relationship between argumentation and critical thinking (Winarti et al., 2021b) or between argumentation and digital literacy (N. O. Putri et al., 2024) in isolation. However, there is a scarcity of research that simultaneously analyzes how critical thinking skills and digital literacy collectively contribute to and influence students' scientific argumentation abilities. This research aims to fill that gap by investigating the integrated relationship between these three essential competencies, providing a more holistic understanding of the factors that underpin effective scientific argumentation in a technology-rich learning environment.

The urgency of addressing this gap is underscored by empirical evidence of students' low argumentation skills. A pre-research study at SMA Negeri 8 Semarang revealed that 74% of students were in the medium to low categories for scientific argumentation. The breakdown by Toulmin's Argumentation Pattern (TAP) components showed particular weakness in providing valid evidence (26%) and constructing rebuttals (19%). Interviews with biology teachers confirmed that students often present unverified information sourced from the internet without critical analysis and struggle to

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formulate coherent arguments. This condition, as noted by Ishaq (Ishaq et al., 2021), stems from a learning process that does not optimally facilitate the development of argumentation skills. Consequently, students face difficulties in managing information, building robust conceptual understanding, and solving complex problems with analytical thinking supported by valid scientific evidence (Amanda et al., 2024).

To address this multifaceted problem, an integrated approach is necessary. The learning process must be designed to simultaneously foster critical thinking and digital literacy as a means to enhance scientific argumentation. This involves implementing student-centered strategies that explicitly train students to critically evaluate information, assess the strength of evidence, and construct logical arguments (Parveen et al., 2024). Furthermore, integrating digital literacy instruction directly into the science curriculum is essential. This would equip students with the skills to efficiently and responsibly search for, select, and utilize credible digital sources to support their claims, reasons, and rebuttals, thereby creating a solid foundation for their argumentation skills (Pinheiro & Santos, 2025).

Based on the background, gap analysis, and identified problems, this research aims to achieve the following objectives: To measure the level of scientific argumentation skills, critical thinking skills, and digital literacy among students at SMA Negeri 8 Semarang; To analyze the relationship between critical thinking skills and students' scientific argumentation abilities; To analyze the relationship between digital literacy and students' scientific argumentation abilities; To investigate the collective contribution of critical thinking skills and digital literacy to the development of scientific argumentation skills. By achieving these objectives, this study is expected to provide empirical insights and a strategic framework for educators to enhance students' scientific argumentation through the synergistic development of critical thinking and digital literacy (Gilal et al., 2020).

RESEARCH METHODS

This study employed a quantitative method with a correlational design. The research aimed to explain the relationship between two independent variables—digital literacy (X1) and critical thinking skills (X2)—and the dependent variable—scientific argumentation skills (Y) among eleventh-grade students. The operational stages of the

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research were as follows: (1) Preparation: literature study, instrument development, and validation; (2) Implementation: sample selection, data collection through tests and questionnaires; (3) Data Analysis: conducting prerequisite tests and hypothesis testing; and (4) Conclusion Drawing: interpreting the results to answer the research hypotheses.

This study was conducted at SMA Negeri 8 Semarang in May of the 2024/2025 academic year. The population was all eleventh-grade students enrolled in Biology, totaling 107 students from three classes. The sampling technique was purposive sampling. The basis for determining the sample was an equivalence test of students' prior learning outcomes using the Kruskal-Wallis test. The results indicated that not all classes were equivalent ($p < 0.05$). A follow-up analysis with an independent samples t-test showed that classes XI.1 and XI.2 were part of an equivalent group ($p > 0.05$), and were therefore selected as the research sample as they were deemed representative of the population. The total number of students from these two classes was 69.

The subject matter used in this study was Environmental Change and Waste Recycling**,** a topic within the Biology curriculum for eleventh grade. This material was chosen because it contains contemporary issues that allow students to explore various perspectives, analyze evidence, and construct arguments, making it highly relevant for measuring critical thinking and scientific argumentation skills.

Data were collected using test and non-test techniques. (1) Scientific Argumentation Skills Test (Y): This essay test was designed to measure students' ability to construct arguments based on Toulmin's Argumentation Pattern (TAP), which includes the indicators of *claim, data (evidence), warrant (reasoning), backing*, and *rebuttal*. Students were presented with a case study on an environmental issue and asked to analyze it and provide a written argument. (2) Critical Thinking Skills Test (X2): This essay test was developed based on Facione's (2015) critical thinking indicators, which include *interpretation, analysis, evaluation, inference, explanation,* and *self-regulation*. The test consisted of problem scenarios that required students to analyze information, evaluate evidence, and draw logical conclusions. (3) Digital Literacy Questionnaire (X1): This non-test instrument was a Likert-scale questionnaire used to obtain data on students' digital literacy. The instrument was adapted from (Agnafia, 2019) and covered

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four key dimensions: (a) information and data literacy, (b) communication and collaboration, (c) digital content creation, and (d) safety and problem-solving.

All research instruments (tests and questionnaire) were validated by two experts in Biology Education and Educational Evaluation. The validation process assessed content validity, construction validity, and language clarity. Furthermore, the tests were piloted on a separate group of students to estimate their reliability using Cronbach's Alpha, with a reliability coefficient of > 0.70 considered acceptable. Data analysis was performed using statistical tests in SPSS 27, proceeding through two main stages: Prerequisite Tests**:** Normality Test; Linearity Test, Multicollinearity Test, Heteroscedasticity Test. and hypothesis testing with: Partial Correlation Test (t-test), Simultaneous Correlation Test (F-test), Multiple Linear Regression Analysis, Coefficient of Determination (R^2).

The research hypotheses tested were:

1. H_0 [1]: There is no significant relationship between digital literacy and the scientific argumentation skills of grade XI students.
   H_a[1]: There is a significant relationship between digital literacy and the scientific argumentation skills of grade XI students.
2. H_0 [2]: There is no significant relationship between critical thinking skills and the scientific argumentation skills of grade XI students.
   H_a[2]: There is a significant relationship between critical thinking skills and the scientific argumentation skills of grade XI students.
3. H_0 [3]: There is no significant relationship between digital literacy and critical thinking skills simultaneously with the scientific argumentation skills of grade XI students.
   H_a[3]: There is a significant relationship between digital literacy and critical thinking skills simultaneously with the scientific argumentation skills of grade XI students.

RESULTS AND DISCUSSION

The analysis began by testing the classical assumptions to ensure the validity of the regression model. The normality test using Kolmogorov-Smirnov yielded a significance value of 0.200 ($p > 0.05$), indicating that the residual data were normally distributed (Ghasemi & Zahediasl, 2012). The linearity test for the relationship between digital literacy (X1) and scientific argumentation skills (Y) showed a significance of 0.801 ($p > 0.05$), confirming a linear relationship between these variables. Furthermore,

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the multicollinearity test revealed a Tolerance value of 0.991 and a Variance Inflation Factor (VIF) of 1.009. Since these values are within acceptable limits (Tolerance > 0.10 and VIF < 10.0), it was concluded that there was no multicollinearity between the independent variables, meaning each variable provides unique information to the model (Pallant et al., 2005). Finally, the heteroscedasticity test using the Glejser test resulted in significance values of 0.414 for digital literacy and 0.418 for critical thinking skills ($p > 0.05$ for both), confirming that the residuals were homoscedastic and thus, the regression model is reliable for prediction (Gujarati & Porter, 2013).

The primary objective of this study was to determine the relationship between digital literacy (X1) and critical thinking skills (X2) with scientific argumentation skills (Y). The hypothesis testing results are summarized below. The partial T-test was conducted to assess the individual relationship of each independent variable with the dependent variable. The results, as shown in Table 1, provide critical insights.

Table 1 Partial t-Test Results

Coefficients[a]

Model		Unstandardized Coefficient		Standardized Coefficient	t	Sig.
		B	Std Error	Beta		
1	(Constant)	88.043	10.038		8.771	<,001
	Digital Literacy	-.498	.116	-.431	-4.285	<,001
	Critical Thinking Skills	.338	.079	.432	4.292	<,001

Table 1 demonstrates that digital literacy exhibits a significant negative relationship with students' scientific argumentation skills ($B=-0.498$, $p<0.05$), whereas critical thinking skills show a significant positive impact ($B=0.338$, $p<0.05$), suggesting that increased digital literacy alone may inadvertently reduce the quality of students' scientific arguments, while strong critical thinking consistently enhances it. This counterintuitive result has been noted in recent literature, such as Hatlevik et al. and List, which emphasize that without sufficient critical evaluation, digital proficiency may lead

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to superficial information use that weakens argumentation quality. Therefore, meaningful improvements in educational settings should not only enhance digital access, but focus on integrating "critical digital literacy" skills—training students to evaluate sources and construct evidence-based arguments for stronger scientific reasoning (Hatlevik et al., 2015; List et al., 2020).

The simultaneous F-test was used to determine if digital literacy and critical thinking skills collectively influenced scientific argumentation skills. The results are presented in Table 2.

Table 2 Simultaneous F Test

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig
1.	Regression	1920.942	2	960.471	16.825	<,001[b]
	Residual	3767.609	66	57.085		
	Total	5688.551	68			

As shown in Table 2, the significance value for the F-test is 0.001 ($p < 0.05$). This leads to the rejection of the null hypothesis (H_0 [3]), confirming that digital literacy and critical thinking skills together have a statistically significant relationship with scientific argumentation skills (Ghozali, 2018).

To predict the value of the dependent variable and understand the individual contribution of each predictor, a multiple linear regression analysis was performed. The coefficients for the regression equation are presented in Table 3.

Table 3 Multiple Regression Test Results

Coefficients[a]

Model		Unstandardized Coefficient		Standardized Coefficient	t	Sig.
		B	Std Error	Beta		
1	(Constant)	88.043	10.038		8.771	<,001
	Digital Literacy	-.498	.116	-.431	-4.285	<,001
	Critical Thinking Skills	.338	.079	.432	4.292	<,001

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The results of the data analysis are listed in Table 3, which shows that the coefficient value of the digital literacy variable is -0.498 and the value of critical thinking skills is 0.338 with a constant number of 88.043. Based on the results obtained, the regression equation is compiled as follows (Gallea, 2023).

$$Y = 88{,}043\ (a) - 0{,}498\ (X_1) + 0{,}338\ (X_2)$$

Based on the regression equation above, it is known that the constant of 88.043 means that if digital literacy and critical thinking skills are zero (0) or fixed, then the value of scientific argumentation skills is 88.043. The coefficient value of X1 is -0.498 which indicates that if the digital literacy variable (X1) increases by one point, there will be a decrease in points on the scientific argumentation variable (Y). The coefficient value of X2 of 0.338 indicates that if the critical thinking skills variable (X2) increases by one point, there will also be an increase in the score on the scientific argumentation skills variable (Y) by 0.338, assuming the value of other variables is constant (Gallea, 2023).

The coefficient of determination is used to determine the contribution of the predictor variables to the criterion variables. The results of the coefficient of determination test are listed in Table 4 below.

Table 4 Results of the Determination Coefficient Test

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.581[a]	.338	.318	7.555

Based on the test results in Table 4, it is known that the adjusted R square is 0.318, it can be concluded that the contribution of digital literacy and critical thinking skills to scientific argumentation skills is 31.8%, while 68.2% is influenced by other factors not studied by the researcher (Raykov & DiStefano, 2025). Correlation test to determine the relationship between each indicator of digital literacy and scientific argumentation skills and to determine the relationship between each indicator of critical thinking skills and scientific argumentation skills. Digital literacy and scientific argumentation skills.

Table 5 Correlation Test Results for Each Indikator

Indicators	KA1	KA2	KA3	KA 4
LD1	-0,052	-0,135	-0,187	-0,028

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Indicators	KA1	KA2	KA3	KA 4
LD2	-0,170	0,055	-0,383	-0,193
LD3	-0,187	-0,107	-0.303	-0,091
LD4	-0,243	-0,154	-0,310	-0,373

Description

LD1 : digital literacy indicator 1
KA1 : argumentation skills indicator 1

Critical thinking skills with scientific argumentation skills

Tabel 6 Correlation Test Results for Each Indikator

Indicators	KA1	KA2	KA3	KA 4
KBK1	-0,121	0,323	0,216	0,242
KBK2	-0,067	0,014	-0,050	0,149
KBK3	0,086	0,067	0.279	0,071
KBK4	-0,090	0,254	0,020	0,337
KBK5	0,206	-0,102	0,172	0,335
KBK6	-0,014	0,060	0,143	0,223

Description

KBK1 : critical thinking skills indicator 1
KA1 : argumentation skills indicator 1

The strong positive relationship between critical thinking and scientific argumentation is a central finding of this research. This result corroborates the state of the art presented in the introduction, which highlighted that constructing logical arguments requires the ability to analyze, evaluate, and infer (Amanda et al., 2024; Facione & Gittens, 2016). In the context of this study, students who excelled at interpretation and evaluation were better equipped to identify relevant evidence and construct coherent reasoning to support their claims, directly enhancing their argumentation quality. This finding is in clear agreement with previous studies by Sumarni and Winarti (Sumarni et al., 2017; Winarti et al., 2021a), reinforcing the notion that critical thinking is an indispensable pillar for developing argumentation skills.

The negative relationship between digital literacy and scientific argumentation skills is a counterintuitive and critical finding. While digital literacy is theorized to aid in sourcing information (N. O. Putri et al., 2024; Repi et al., 2024b), the data suggests

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that mere access and technical proficiency are insufficient. A plausible explanation for this paradox lies in the nature of students' digital engagement. The negative correlation may indicate that students, despite being digitally literate, are not necessarily *critically* literate. They might be skilled at finding information online but lack the advanced critical thinking required to discern credible sources from misinformation or to synthesize information into a structured argument (Silalahi et al., 2022). In this scenario, high digital literacy without commensurate critical evaluation skills could lead to the collection of unverified or irrelevant evidence, ultimately weakening their scientific arguments. This interpretation is supported by the pre-research interview, where teachers noted that students often presented unverified information from the internet.

The correlation tests at the indicator level (Tables 5 & 6 in the original) provide a more granular view. The predominantly weak and negative correlations between specific digital literacy indicators (e.g., information searching, content creation) and argumentation indicators (claim, evidence, reasoning) strengthen the argument that digital skills alone do not translate to better argumentation. Conversely, the mixed but generally more positive correlations between critical thinking indicators (e.g., analysis, inference) and argumentation components align with the overall positive relationship, though the weakness of some correlations suggests that not all critical thinking sub-skills were equally developed or measured effectively.

This finding partially contradicts studies that posit a straightforward positive relationship between digital literacy and argumentation (Kurniawan & Sarah, 2023). It suggests that the relationship is more nuanced. Digital literacy may be a necessary but insufficient condition; its value is fully realized only when coupled with strong critical thinking to filter and apply the information obtained.

Strengths, Weaknesses, and Implications

A key strength of this study is its simultaneous investigation of two crucial 21st-century skills, revealing their complex interplay rather than examining them in isolation. However, a limitation is that it was conducted in a single school, which may affect the generalizability of the results. Furthermore, the cross-sectional design cannot establish causality. The implications of this research are significant for educational practice. Firstly, it strongly advocates for the explicit integration of critical thinking exercises

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into science curricula, using models like Ethno-ECLIPSE or contextual approaches, as suggested by prior studies. Secondly, it calls for a re-evaluation of how digital literacy is taught. Instead of focusing solely on technical skills, instruction must emphasize *critical digital literacy*—teaching students to evaluate online sources critically, verify information, and use digital tools ethically and effectively to build knowledge (Hague & Payton, 2010). This integrated approach is essential for preparing students to become not just consumers of information, but critical thinkers and compelling communicators in the digital age.

The Interplay of Digital Literacy, Critical Thinking, and Scientific Argumentation

The analysis of individual indicators provides a deeper, more nuanced understanding of the significant relationships revealed by the regression model. The negative correlation between digital literacy and scientific argumentation skills presents a complex picture that warrants detailed exploration. The data suggests that this counterintuitive finding stems not from digital literacy being inherently detrimental, but from how students *apply* their digital skills in the absence of strong critical filters. For instance, the weak negative correlation ($r = -0.028$) between internet search skills and the ability to formulate rebuttals indicates that while students can easily find information online, they struggle to verify its accuracy. This often results in rebuttals based on incorrect or unreliable evidence, ultimately weakening their scientific arguments. This aligns with the pre-research observations at SMA Negeri 8 Semarang, where teachers noted a tendency for students to use unverified information from the internet. These findings appear to contradict the common assumption that digital literacy automatically improves academic reasoning. However, several studies have shown that digital literacy is not always directly proportional to critical and argumentative thinking skills. Digital literacy often remains at the operational level, such as the ability to access and use technology, without being accompanied by an in-depth evaluation of information (Subaveerapandiyan & Sinha, 2022). Furthermore, digital literacy that is not integrated with critical thinking skills is less effective in improving the quality of students' argumentative writing (Haliq et al., 2025). In fact, without critical digital literacy, individuals tend to be more susceptible to misinformation, which ultimately weakens the quality of scientific judgment and argumentation (McGrew & Kohnen, 2024; McGrew & Breakstone, 2023). Therefore,

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digital literacy needs to be understood as a multidimensional construct encompassing technical, cognitive, and critical aspects, not simply the ability to use technology (Tinmaz et al., 2022). Thus, the negative relationship that emerged was not caused by digital literacy itself, but rather by its application, which was not accompanied by a strong critical filter in the scientific argumentation process.

Similarly, the negative relationship between the ability to evaluate information content (r = -0.091) and the rebuttal indicator points to a crucial deficiency. Students often fail to distinguish between fact and opinion or trace the origin of information, leading them to use content without comparison to more reliable sources (Sholcha et al., 2024). The most substantial negative correlation was found between the ability to compile knowledge and the evidence indicator (r = -0.154). This suggests that students often collect information from various digital sources without deeply engaging with or verifying the original sources, leading to evidence that is superficial or invalid (Alawiyah et al., 2023; Hasliyah, 2022). This compilation without critical evaluation renders their digital literacy counterproductive for constructing robust scientific arguments.

Conversely, the analysis solidly confirms the pivotal role of critical thinking. The positive correlations between specific critical thinking indicators and argumentation components reveal the mechanistic link. For example, the correlation between basic clarification and evidence (r = 0.323) demonstrates that the ability to test initial information helps students gather and structure valid evidence (Kuhn, 2015). Furthermore, the relationship between decision-making and rebuttal (r = 0.149) underscores that formulating a strong rebuttal requires a balanced analysis of supporting and opposing arguments, a core aspect of decision-making (Inch et al., 2006). The correlation between drawing conclusions and reasoning (r = 0.279) shows that sound conclusions are built upon logical reasoning, which is strengthened by critical thinking (Syifa Lailatul Mutmainnah et al., 2021). The strongest relationships were observed between advanced skills like making further clarifications (r = 0.337) and integration (r = 0.335) with the rebuttal indicator, highlighting that the ability to analyze arguments from multiple perspectives and integrate diverse information is essential for constructing powerful counter-arguments (Resky, 2023).

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Synthesis, Comparison with Previous Research, and Limitations

The regression model, Y = 88.043 - 0.498(X1) + 0.338(X2), and the coefficient of determination (31.8%) crystallize the findings: critical thinking is a strong, direct driver of scientific argumentation, while the role of digital literacy is conditional and potentially negative if not paired with critical evaluation. This finding creates a compelling dialogue with the state of the art. It strongly aligns with research by Winarti et al. (2021) and Dewi et al. (2023) on the fundamental connection between critical thinking and argumentation. However, it introduces a critical contradiction or at least a significant refinement to studies that propose a straightforward positive relationship between digital literacy and argumentation (N. O. Putri et al., 2024). This study demonstrates that the optimistic view of digital literacy's role is incomplete; its benefits are not automatic and are mediated by the user's critical thinking capacity. This explains the "paradox" where high digital literacy does not guarantee high argumentation skills, a phenomenon also noted in broader educational technology research (Reddy et al., 2022). The findings suggest that in the Indonesian context, digital access may sometimes be channeled towards social recognition rather than educational productivity, limiting its impact on academic skills like argumentation (Nasrulloh, 2016).

CONCLUSION

This study conclusively establishes the complex dynamics between digital literacy, critical thinking, and scientific argumentation skills, revealing a significant positive relationship between critical thinking and argumentation that solidifies its role as foundational, while simultaneously demonstrating a counterintuitive negative relationship between digital literacy and argumentation skills that challenges conventional assumptions about digital proficiency. The regression model confirms these two variables collectively explain 31.8% of variance in argumentation skills, with the remaining 68.2% attributable to other factors including motivation, prior knowledge, and pedagogical approaches. These findings necessitate a strategic pedagogical shift toward: explicitly integrating critical thinking exercises in science curricula; transforming digital literacy instruction from technical training to critical digital literacy emphasizing source evaluation and analytical inquiry; and developing synergistic teaching models that concurrently cultivate critical thinking and digital literacy. Future research should focus on refining digital literacy measurement instruments and

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investigating the substantial unexplained variance in argumentation skills, particularly examining how classroom dynamics and specific instructional strategies might mediate these relationships.

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