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The Silent Catalysts: How Engagement in Blended Learning Shapes Science Students' Critical Thinking

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Abstract

Blended learning becomes a central post-pandemic instructional model and understanding how learners engage within these environments is important for enhancing higher-order thinking skill. This study examines the extent to which students' blended learning engagement predicts the critical thinking skills of high school science students, and whether socioeconomic status (SES) moderates this relationship. A quantitative correlational design was employed, involving 469 science students from Indonesian high schools that have consistently implemented blended learning. Data were collected through a 4-point Likert-scale questionnaire and analyzed using Spearman's rank-order correlation and bootstrap regression. The results indicated that cognitive engagement was the strongest predictor of critical thinking ($\rho = .793$, $p < .001$; $\beta = .751$, $p < .001$), while emotional engagement had a positive but smaller effect ($\rho = .291$, $p < .001$; $\beta = .066$, $p = .029$), and behavioral engagement was insignificant ($\rho \approx .000$, $p = .998$; $\beta = –.028$, $p = .326$). Simultaneously, the three dimensions of engagement explained 59.9% of the variability in critical thinking, with no significant moderating effect of SES. However, split-group correlations indicated that the correlation between blended learning engagement and critical thinking was stronger among students from low- ($\rho = .512$) and high- ($\rho = .481$) SES groups compared to those from the middle group ($\rho = .386$), indicating variation in effect magnitude but not direction, thereby clarifying the apparent contradiction with the non-significant moderation test. These findings confirmed cognitive engagement as the core component of reflective learning in blended learning, as well as highlighted the need for instructional designs that strengthen metacognitive regulation and epistemic autonomy for diverse learners.

Keywords: *Blended Learning Engagement; Critical Thinking; Distance Learning; Online Learning; Science Students*

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INTRODUCTION

The COVID-19 pandemic has made a significant shift in the global education system, compelling institutions worldwide to shift from face-to-face learning to fully online instruction. This transition was not merely technical, it disrupted pedagogical foundations and accelerated the integration of digital technologies into daily teaching and learning process (Adedoyin & Soykan, 2023; Almahasees et al., 2021). In the post-pandemic context, blended learning model, which systematically combine face-to-face and online modalities, has emerged as a long-term solution promising flexibility, personalization, and effectiveness (Bashir et al., 2021;

Hujjatusnaini et al., 2022). However, the implementation of blended learning does not automatically guarantee meaningful student learning. One of the main challenges is student engagement, particularly in blended learning environments that demand high levels of independence and digital literacy (Dillenbourg, 2016; Salas-Pilco et al., 2022).

In the context of blended learning, student engagement unfolds across three interrelated dimensions: emotional, cognitive, and behavioral (Fredricks et al., 2004). Emotional engagement reflects students' positive feelings toward learning, such as interest and enthusiasm. Cognitive engagement involves the strategic investment students make in mastering the learning content through deep thinking. Moreover, behavioral engagement is evident in students' observable actions, such as completing tasks, discussions, and attending class regularly (ElSayary, 2023; Fredricks et al., 2004; Halverson & Graham, 2019). Research has shown that high levels of engagement can improve student motivation, knowledge retention, and academic achievement, both in online and face-to-face contexts (D. Pagcamaan, 2024; Iglesias-Pradas et al., 2021). However, the combination of physical and digital learning spaces in blended learning introduces new challenges. The tensions between technological demands, learning autonomy, and reduced social interaction may undermine student engagement if not thoughtfully addressed (Castro, 2019; D. Pagcamaan, 2024; Rasheed et al., 2020). Therefore, understanding engagement as a multidimensional and context-sensitive phenomenon is key to ensuring that blended learning supports meaningful and transformative learning experiences.

Amid the flux of 21st century education, critical thinking skills has been recognised as a fundamental intellectual disposition. In science education particularly, it enables students to evaluate information, construct evidence-based arguments, and make reflective and informed decisions (García-Carmona, 2025; Pasquinelli et al., 2021). Blended learning, with its potential for interactive, flexible, and resource-rich environments, is seen as a promising ecosystem for the development of critical thinking. However, research increasingly suggested that simply adopting a blended learning model does not directly translate to improvement of students' critical thinking skills, what matters is how students are engaged within the learning environments (D. Pagcamaan, 2024; de Bruin et al., 2025). Unfortunately, the relationship between student engagement in blended learning and their critical thinking skills remains understudied, particularly among science students.

Most studies still examine students' engagement and critical thinking separately, or treat them as static traits (Chang et al., 2021). Students' engagement is frequently measured through participation levels without considering their emotional, cognitive, and behavioral dimensions (Chin et al., 2025). Likewise, studies on critical thinking often focus on curriculum-based interventions or specific teaching methods, overlooking how students' active involvement in the learning process contributes to shaping their thinking skills (Qureshi et al., 2016). Moreover, in Indonesian contexts, where systemic inequalities shape students' learning opportunities, socioeconomics status (SES) is rarely considered as a moderating variable, even though the literature shows that SES can influence access to digital tools, the quality of student engagement, and their learning outcomes (Azubuike et al., 2021; Qaribilla et al., 2024; Scherer & Siddiq, 2019). This gap has

the potential to result in a biased understanding of how blended learning operates in practice and could widen existing educational disparities. Taken together, these gaps show a clear research problem: blended learning requires engagement and critical thinking but few studies have empirically examined how the three dimensions of engagement simultaneously affect critical thinking and SES moderation has rarely been tested. This creates a missing link in the literature, particularly in secondary science education where reflective and analytical skills are essential.

This study therefore aims to investigate how student engagement in blended learning (emotional, cognitive, and behavioral) contributes to their critical thinking skills. Furthermore, it also examines the role of socioeconomic status (SES) as a moderating variable that potentially influences the strength of this relationship. Using a quantitative correlational approach, this study aims to answer two key questions: (1) To what extent does each dimension of engagement influence students' critical thinking skills?, and (2) Does the strength of this influence differ across SES groups? The findings of this study are expected not only to enrich the theoretical discourse of student learning process but also to provide practical contributions for curriculum designers, science teachers, and policymakers in creating blended learning designs that are both cognitively enriching and socially just for the development of 21st-century skills. Based on the research objectives and theoretical foundations outlined, this study proposes the following hypotheses:

1. H1: Emotional engagement in blended learning significantly predicts students' critical thinking skills.
2. H2: Cognitive engagement in blended learning significantly predicts students' critical thinking skills.
3. H3: Behavioral engagement in blended learning significantly predicts students' critical thinking skills.
4. H4: Emotional, cognitive, and behavioral engagement in blended learning simultaneously predict students' critical thinking skills.
5. H5: Socioeconomic status moderates the relationship between student blended learning engagement and critical thinking skills.

METHODS

1. Research Design

This study implemented a non-experimental quantitative design with a correlational-predictive approach. This design was chosen to analyze the extent to which students' engagement in blended learning across dimensions predicts their critical thinking skills, as well as examining the role of socioeconomic status (SES) as a moderating variable. This design is appropriate to observe the natural learning dynamics without involving any manipulations or interventions (Fraenkel et al., 2019).

2. Participants and Research Context

Participants consisted of high school science students in Indonesia who are participating in blended learning environments. The sample was selected

purposively, only for schools that had consistently implemented blended learning model. The questionnaire was administered using Google Form and distributed via WhatsApp to students at the relevant schools. The final number of respondents was 469 students, with diverse socioeconomic backgrounds to allow for moderation analysis. This reseach was conducted in the context of Indonesian education, where the digital inequality remains a salient factor influencing student engagement and learning outcomes.

3. Instrument

Data were collected using a closed-ended Likert-scale questionnaire (1–4), which are divided into three main sections:

1) Student engagement was assessed across three dimensions (Adams et al., 2020) emotional engagement (5 items), cognitive engagement (4 items), and behavioral engagement (7 items).
2) Critical thinking was measured using 6 items based on indicators from (Çevik & Senturk, 2019).
3) Socioeconomic status (SES) was assessed through parents' income which are coded into three categories based on the city's minimum wage (UMR) (low = <1x UMR, middle = 1-2x UMR, high = >2x UMR or above). Although SES consisted of broader dimensions such as parental education and occupation, income was used as the sole indikator due to feasibility and reporting accuracy in large-scale school-based surveys. This constitutes a methodological limitation, as the SES variable may capture a narrower variance than multidimensional SES measures.

Prior to the main data collection, the instrument was tested for its validity and reliability with a sample of 117 students. The content validity of each item was examined through Corrected Item-Total Correlation analysis. An item was declared valid if its Corrected Item-Total Correlation value was greater than the r table at a significance level of 0.05 (N = 117 → table r = 0.1816). As show in Table 1, all items had correlation values above 0.18, ranging from 0.34 to 0.72, indicating that all items in the instrument were valid and suitable for use in research (Field, 2024).

Table 1. Validity Test of The Instrument (Corrected Item-Total Correlation)

Item	Corrected Item-Total Correlation	Description
EE1	.621	Valid
EE2	.580	Valid
EE3	.492	Valid
EE4	.344	Valid
EE5	.437	Valid
CE1	.624	Valid
CE2	.546	Valid
CE3	.492	Valid
CE4	.560	Valid
BE1	.484	Valid
BE2	.511	Valid
BE3	.660	Valid
BE4	.417	Valid
BE5	.571	Valid
BE6	.605	Valid

BE7	.585	Valid
CT1	.719	Valid
CT2	.656	Valid
CT3	.643	Valid
CT4	.649	Valid
CT5	.639	Valid
CT6	.642	Valid

Moreover, the reliability of each scale was tested using Cronbach's alpha, with values ≥ 0.70 considered to meet reliability standards (Field, 2024).

Table 2. Reliability Test of The Instrument

Statistic	Value
Cronbach's Alpha	.916
Cronbach's Alpha Based on Standardized Items	.923
Number of Items	22

Based on the results, all items in the research instrument were both valid and reliable, and therefore suitable for use in the main data collection phase of this study.

4. Data Analysis Techniques

Prior to the main analysis, some assumption tests were conducted. The data was assessed for its normality using Kolmogorov-Smirnov and Shapiro-Wilk normality tests. As the results indicated a non-normal distribution, the Spearman's rank-order correlation was used to examine the relationship between each blended learning engagement (BLE) dimension and critical thinking (CT) skills (H1-H3). For hypotheses H4 (simultaneous influence of BLE to CT) and H5 (moderating role of SES), a linear regression analysis with bootstrap technique was conducted. The bootstrap was set to 1,000 samples and a 95% confidence level. Moreover, for H5 analysis, an interaction term between BLE and SES was constructed. To reduce potential multicollinearity, all predictors were mean-centered prior to generating the interaction term (Field, 2024). Multicollinearity testing was performed by examining the Tolerance and Variance Inflation Factor (VIF) values, which indicated that all predictors were within acceptable levels (Tolerance > 0.20; VIF < 5) and multicollinearity was not a concern. The analysis was conducted using SPSS version 26.

RESULTS & DISCUSSION

Students' Profile of Blended Learning Engagement and Critical Thinking

This study involved 469 high school science students from institutions that have consistently implemented blended learning model. The demographic characteristics of the respondents are shown in Table 3. The majority of participants were female, ranging in age from 15-18 years old. They came from various grade levels and represented a diverse socioeconomic background. This distribution is essential for capturing the variation in students' learning experiences in a blended learning context.

Table 3. Demographic Characteristics of Respondents

Characteristic	Category	Frequency (n)	Percentage (%)
Gender	Male	200	43%
	Female	269	57%
Age	15	65	14%
	16	205	44%
	17	143	30%
	18	56	12%
Grade Level	X	192	41%
	XI	170	36%
	XII	107	23%
Socioeconomic Status	Low	124	26%
	Middle	197	42%
	High	148	32%

The descriptive statistics of the main variables in this study are presented in Table 4. Emotional engagement dimension indicates students' affective responses toward blended learning, such as interest, comfort, and emotional connectedness. Cognitive engagement reflects the extent to which students engage intellectually through deep learning strategies and self-regulation. Behavioral engagement indicates students' active participation in learning activities. The total engagement score is calculated from the combination of these three dimensions and can be seen as Blended Learning Engagement in Table 4. Students' critical thinking skills were measured through six indicators that reflect their ability to analyze, evaluate, and make evidence-based decisions. Students' socioeconomic status (SES) was reported based on students' parental income.

Table 4. Descriptive Statistics of Research Variables

Variabel	Items	Mean	Standard Deviation
Socioeconomic Status (SES)	1	2.05	0.76
Emotional Engagement (EE)	5	2.96	0.54
Cognitive Engagement (CE)	4	3.25	0.34
Behavioral Engagement (BE)	7	3.23	0.34
Blended Learning Engagement (BLE)	16	3.15	0.27
Critical Thinking (CT)	6	3.32	0.44

In general, students demonstrated a fairly high levels of engagement in blended learning, with the Cognitive Engagement dimension (M=3.25, SD=0.34) emerging as the most prominent dimension. Students' critical thinking skills score were at a fairly good level (M = 3.32, SD = 0.44), indicating generally solid capacity for reflective and analytical thinking in the context of blended learning-based science education. Meanwhile, the SES distribution (M = 2.05, SD = 0.76) indicated variations in economic background that are relevant for further analysis in testing the moderating role of the relationship between blended learning engagement and critical thinking skills.

The Relationship of Blended Learning Engagement Dimensions and Critical Thinking (H1-H3)

Table 5. Normality Test for Main Variables

Variable	Kolmogorov–Smirnov (KS)	p-value
EE 1	.381	<.001
EE 2	.356	<.001
EE 3	.311	<.001
EE 4	.304	<.001
EE 5	.308	<.001
CE 1	.400	<.001
CE 2	.456	<.001
CE 3	.509	<.001
CE 4	.482	<.001
BE 1	.467	<.001
BE 2	.496	<.001
BE 3	.452	<.001
BE 4	.519	<.001
BE 5	.474	<.001
BE 6	.453	<.001
BE 7	.464	<.001
CT 1	.404	<.001
CT 2	.439	<.001
CT 3	.436	<.001
CT 4	.440	<.001
CT 5	.444	<.001
CT 6	.429	<.001

The normality of the data was tested using the Kolmogorov-Smirnov method. The results showed that all items in the BLE and CT constructs produced a significance value (p) <0.001, indicating that the data deviated significantly from the normal distribution (Field, 2024). Therefore, the Spearman rank-order correlation method was employed as a non-parametric alternative of correlation test, which offers greater robustness for skewed or non-linear data. This test was used to examine the relationships between the three dimensions of BLE (emotional, cognitive, and behavioral engagement) and students' CT skills in the context of blended learning. Interpretation of the correlation coefficient follows Cohen's (2013) conventional thresholds, where values of $\rho \geq .10$ were considered weak, $\geq .30$ moderate, and $\geq .50$ strong. The significance level was set at $\alpha = .05$, as common standard in educational research (Creswell, 2014). The results are presented in Table 6.

Tabel 6. Spearman's correlation test

Variable	Correlation Coefficient (ρ)	Significance (p)
Emotional Engagement – CT	.291	< .001
Cognitive Engagement – CT	.793	< .001
Behavioral Engagement – CT	.000	.998

The findings indicate that cognitive engagement (CE) has the strongest correlation with critical thinking skills ($\rho = .793$, $p < .001$), confirming that intellectual engagement through higher-order thinking strategies, idea elaboration,

and self-regulation is a key determinant in the development of students' reflective and evaluative thinking skills. In the context of blended learning, which demands high degrees of learners' autonomy, these results suggest that cognitive capacities do not serve as complementary attributes, but rather as central functions mediating the relationship between instructional design and the quality of learning outcomes. This aligns with the notion that cognitive engagement facilitates the activation of executive functions that support meaningful knowledge construction (Li et al., 2023; Papavlasopoulou et al., 2019).

Meanwhile, emotional engagement (EE) also showed a significant correlation with critical thinking ($\rho = .291$, $p < .001$), albeit within the weak to moderate effect size category (Cohen, 2013). These findings support the notion that affective aspects such as interest, comfort, and emotional connectedness can create psychological conditions that support more meaningful learning engagement. In blended learning environments with minimal physical teacher presence, emotional engagement plays a crucial role in fostering a sense of belonging and psychological safety in the learning process (Zhou & Tsai, 2023). Although EE may not directly influence critical thinking capacity, its function as a psychological catalyst that strengthens students' readiness for deeper cognitive activity cannot be overlooked.

In contrast, behavioral engagement (BE) showed no significant relationship with critical thinking ($\rho = .000$, $p = .998$), showing that physical participation in the form of attendance, task completion, or surface participation does not automatically translate to higher-order thinking development. This finding reflects the importance of distinguishing between physically active engagement and cognitively reflective engagement. Li et al. (2023) confirmed that behavioral indicators tend to be weak in predicting complex learning outcomes, particularly in online and blended learning contexts that rely on compliance-based evaluation mechanisms.

Theoretically, these results confirm the framework of Fredricks et al. (2004), which conceptually and methodologically separates engagement dimensions and positions cognitive engagement as the most relevant dimension to higher-order cognitive skills. In a blended learning ecosystem, the significance of cognitive engagement is increasingly prominent because students are required to manage their time, set goals, and reflect on their learning process independently. Therefore, instructional practices that relies solely on behavioral participation or emotional affect is insufficient to optimally foster the development of critical thinking.

The practical implications of these findings lies in the imperative to design learning strategies that go beyond promoting attendance or superficial participation, but also explicitly foster their cognitive capacity. The integration of inquiry-based approaches, problem-based learning (PBL), and metacognitive scaffolding is relevant for creating a learning environment that encourages elaboration, synthesis, and in-depth reflection, key competencies in developing critical thinking skills in science students in the digital age.

Collective Contribution of Blended Learning Engagement to Critical Thinking Skills (H4)

Before conducting the regression analysis, a multicollinearity assumption test was conducted to ensure the absence of strong linear relationship among the predictor variables. The results indicated that all independent variables (Emotional

Engagement (EE), Cognitive Engagement (CE), and Behavioral Engagement (BE)) had Tolerance values > 0.85 and VIF values < 10 indicating that multicollinearity was not an issue (Hair et al., 2009). Thus, all variables could be included in the regression model without violating the linearity assumptions.

Furthermore, a multiple regression analysis with a bootstrap method (1,000 resamplings) was conducted to estimate the collective contribution of the three dimensions of BLE to students' critical thinking skills. This test found that the overall regression model was significant ($F(3,465) = 231.63$, $p < .001$) with an R^2 value of 0.599, indicating that approximately 59.9% of the variability in critical thinking skills could be explained by the three dimensions of BLE simultaneously. These results indicate that overall learning engagement (emotional, cognitive, and behavioral) contributes significantly to the development of students' critical thinking skills in the context of blended learning.

Table 6. Bootstrap Regression Results between Engagement and Critical Thinking Dimensions

Variabel	B	SE	β	Sig.
(Constant)	-0.081	0.145	—	.611
Behavioral Engagement (EE)	-0.023	0.024	-0.028	.326
Cognitive Engagement (CE)	**0.983**	0.034	**0.751**	**< .001**
Emotional Engagement (BE)	**0.086**	0.039	0.066	**.029**

The results showed that Cognitive Engagement (CE) remains the most dominant predictor, confirming that intellectual engagement, through deep thinking strategies, conceptual elaboration, and metacognitive reflection, is central to the development of higher-order thinking skills (Kay et al., 2019; Li et al., 2023). In contrast, Behavioral Engagement (BE) yields a very small negative coefficient ($B = –0.023$), which is consistent with the correlation analysis ($\rho = .000$) and indicates that superficial behavioral engagement such as attendance and participation does not necessarily correlate with the depth of cognitive processing (Li et al., 2023; Yang et al., 2025). Meanwhile, Emotional Engagement (EE) provides a smaller but positive contribution ($p = .029$; $\beta = .066$), suggesting that affective factors such as interest, enthusiasm, and enjoyment of learning function as psychological enablers that strengthen students' cognitive readiness for reflective thinking (Akpinar & Aslan, 2015; Zhou & Tsai, 2023). These results are consistent with the Spearman correlation analysis (H1–H3), in which cognitive engagement exhibited the strongest relationship with critical thinking skills, emotional engagement had a moderate relationship, and behavioral engagement showed insignificant association. Hence, these regression results further confirm that the collective contribution of blended learning engagement to critical thinking skills is primarily driven by the cognitive dimension.

Overall, the bootstrap results reinforce previous correlation findings and confirm that the cognitive dimension serves as the structural core of blended learning engagement, while the emotional and behavioral dimensions serve as a supporting context that facilitates intellectual engagement. Engagement is not an additive construct, but rather a hierarchical one, with the cognitive dimension central to the transformation of affect and behavior into meaningful intellectual performance (Fredricks et al., 2004; Li et al., 2023). Consequently, effective

blended learning should cultivate a deliberate balance between cognitive depth and emotional resonance, ensuring that student engagement does not stop at the level of participation but rather transforms into a reflective, meaningful, and sustainable learning experience. Future studies may employ structural equation modeling (SEM) to examine whether EE and BE exert indirect effects through CE, offering further clarity on the pathways through which engagement dimensions influence critical thinking. This integration not only strengthens critical thinking skills as a core competence of the 21st century but also repositions blended learning as a transformative space for cultivating students who are intellectually independent and emotionally grounded.

The Role of Socioeconomic Status (SES) in the BLE-CT Relationship

Before testing the moderating effect, a multicollinearity test was also conducted on the regression model involving Blended Learning Engagement (BLE), Socioeconomic Status (SES), and the BLE × SES interaction. The results showed that all predictors had Tolerance values > 0.95 and VIF values < 1.1, indicating the absence of serious multicollinearity issue (Field, 2024). Thus, the regression model was deemed suitable for interaction testing. A moderation analysis using the bootstrap method (1,000 resamplings) indicated that BLE significantly predicted students' critical thinking skills (B = 0.759, p < .001), while SES neither exerted a direct effect (B = 0.041, p = .884) nor an interaction effect (B = –0.014, p = .876). Statistically, the BLE–CT relationship remained consistent across all SES levels (see Table 7).

Table 7. Bootstrap Regression for SES Moderation on the BLE-CT Relationship

Variabel	B	SE	Sig.	95% CI Lower	95% CI Upper
BLE Total	**0.759**	0.162	< .001	0.424	1.053
SES	0.041	0.286	.884	-0.418	0.501
BLE × SES	-0.014	0.089	.876	-0.162	0.139

Model summary: $R = 0.447$, $R^2 = 0.200$, $F(3,465) = 38.718$, $p < .001$

To further investigate the relationship patterns across socioeconomic groups, a Spearman's correlation analysis using the split-file technique was also conducted, comparing the strength of the BLE-CT relationship across the three SES levels. The results are presented in Table 8.

Table 8. Spearman's Correlation between BLE and CT by SES Group

SES Group	N	ρ (Spearman)	Sig. (2-tailed)
Low	124	**.512**	< .001
Middle	197	**.386**	< .001
High	148	**.481**	< .001

Although the bootstrap moderation tests indicated that SES did not significantly alter the direction or strength of the BLE-CT relationship, the correlation pattern in Table 7 reveals a more nuanced picture. The relationship between BLE and critical thinking remained significant across all SES groups, yet stronger for students with low- and high-SES backgrounds than for the middle-SES group. This pattern indicates that SES may not act as a structural differentiator but

rather as a contextual amplifier, strengthening the engagement impact when certain motivational or environmental supports are present (Bohnert & Gracia, 2023; Scherer & Siddiq, 2019).

The highest correlation in the low-SES group (ρ = .512) suggests that when learning opportunities were provided through a flexible and reflective blended platform, students with limited economic resources may experience relatively greater cognitive benefits. It resonates with the "equalizing potential" argument of digital learning (Azubuike et al., 2021; Bohnert & Gracia, 2023; Qaribilla et al., 2024), which emphasizes that technology-mediated engagement can reduce social inequality by increasing learning autonomy and access to open resources. In this case, learning engagement acts as a compensatory mechanism that offsets the disadvantages associated with lower social or economic capital (Bohnert & Gracia, 2023; Qaribilla et al., 2024). Conversely, the lowest correlation in the middle-SES group (ρ = .386) may reflect a saturation effect: this group may have relatively good access to technological resources but lack the strong intrinsic drive to maximize learning opportunities (Bach et al., 2025). Meanwhile, the high SES group (ρ = .481) shows a strong relationship likely because of their well-established access and self-regulated learning capacity, making engagement a means to actualize higher cognitive potential (Azubuike et al., 2021; Scherer & Siddiq, 2019). These results enrich the ongoing discourse that the influence of SES on technology-based learning is nonlinear. As stated by Azubuike et al. (2021), Bohnert & Gracia (2023), and Qaribilla et al. (2024) the effect of SES in the context of digital learning is more dependent on the interaction between technological affordances and learner agency than on material access alone. Thus, although SES was not statistically proven to be a moderator, it remains a dynamic setting that influences how students from different economic groups interpret and utilize engagement in the learning process.

Theoretically, these findings support Fredricks et al.'s (2004) framework that engagement is multidimensional and may bridge external social factors and internal cognitive outcomes. Cognitive engagement, which proved as the most dominant factor in this study, appears to function as an epistemic equalizer, enabling students from different SES backgrounds to access equal reflective thinking processes.

Practically, these results emphasize the importance of designing human-centered and digitally equitable blended learning environments, which provide emotional support and cognitive scaffolding to students from lower SES groups without compromising academic rigor. Instrutcional strategies such as guided inquiry, problem-based learning (PBL), and reflective dialogue can serve as learning catalysts that simultaneously integrate cognitive and socio-emotional dimensions (Azubuike et al., 2021; Bohnert & Gracia, 2023; Qaribilla et al., 2024)

Ultimately, while SES does not act as a formal moderator, the results demonstrate the unique equalizing potential of blended learning, enabling engagement to become a transformative tool for students across social classes. In the context of science education, this emphasizes that what matters most is not students' economic background, but rather students' reflective capacity to engage deeply in meaningful learning as an intellectual and human endeavor.

Synthesis and Educational Significance

The findings of this study confirm that student engagement within blended learning contexts acts as a primary catalyst for developing critical thinking skills in science students. The analyses indicate that the cognitive dimension is at the core of this mechanism, functioning as an epistemic foundation that connects the emotional and behavioral aspects to higher intellectual achievement (Li et al., 2023; Papavlasopoulou et al., 2019).

Theoretically, engagement functions as an epistemic bridge that channels social and emotional influences toward cognitive achievement. Cognitive engagement emerges as the primary driver in the construction of reflective knowledge that transcends socioeconomic differences. In this context, blended learning carries an equalizing potential, where active digital participation can reduce social inequality by increasing learning autonomy and access to open resources (Bohnert & Gracia, 2023; Scherer & Siddiq, 2019).

Practically, blended learning-based science instruction needs to be designed in a human-centered and digitally equitable manner, balancing cognitive stimulation with emotional support. Approaches such as problem-based learning (PBL), guided inquiry, and reflective scaffolding are effective in fostering reflective engagement while strengthening higher-order thinking skills (Azubuike et al., 2021; Bohnert & Gracia, 2023; Qaribilla et al., 2024). Thus, blended learning effectiveness depends not on the digital platform itself but on how instructional design activates autonomous, reflective, and sustained critical thinking processes.

CONCLUSION

This research shows that student engagement in blended learning is a key determinant of critical thinking development especially for science students, with the cognitive dimension emerging as the most dominant factor. While the emotional and behavioral engagement remain important, they serve more as a supporting context that facilitates intellectual engagement to develop optimally. Socioeconomic status (SES) did not statistically moderate the relationship between blended learning engagement and critical thinking relationship, yet it continues to serve as a dynamic context influencing how students interpret and utilize digital learning opportunities.

The implications of these findings extend to both science education and educational design, emphasizing that equitable blended learning can become a transformative space where engagement connects social inequality and increases epistemic justice. Blended learning designed with humanistic and reflective principles has the potential to improve students' 21st-century competencies, intellectualy autonomy, and emotional groundedness.

Nevertheless, it should be noted that the correlational research design in this study limits causal inference. Further research is recommended using longitudinal or mixed methods designs to understand the temporal dynamics of learning engagement and critical thinking. Empirical studies employing deep engagement interventions are also recommended to evaluate the effectiveness of interventions

designed to strengthen reflective processes and higher-order thinking across various educational contexts.

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