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Equity-Focused Inquiry Pedagogy: Linking Engagement to Scientific Literacy in Ghanaian Senior High Schools

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Abstract: This study investigated the impact of inquiry-based learning (IBL) on scientific literacy (SL) among Ghanaian senior high school students, with learner engagement (LE) serving as a mediator and gender and socioeconomic status (SES) acting as moderators. A cross-sectional survey was conducted using multistage sampling to select 400 senior high school students. Bootstrapped mediation analysis and Ordinary Least Squares regression were utilised for data analysis. The findings indicated that IBL significantly predicted learner engagement ($\beta = 0.47$, $p < .001$) and scientific literacy ($\beta = 0.31$, $p < .001$): For every 1 standard deviation increase in IBL, learner engagement increases by 0.47 standard deviations, while scientific literacy increases by 0.31 standard deviations, holding other variables constant. Furthermore, learner engagement was found to be a strong predictor of scientific literacy ($\beta = 0.42$, $p < .001$), indicating a moderate-to-strong effect, whereby every 1 standard deviation increase in learner engagement corresponds to an increase of 0.42 standard deviations in scientific literacy, controlling for other variables. Additionally, the mediation pathway (IBL → LE → SL) was significant, providing partial mediation with a substantial effect size ($\beta = 0.20$, 95% CI [0.11, 0.32]). Lastly, separate moderation analyses revealed significant effects across subgroups. The gender association was stronger for females (B = 0.49, $p < .001$) compared to males (B = 0.34, $p < .001$), while socioeconomic status was more pronounced among high-SES students (B = 0.58, $p < .001$) than low-SES students (B = 0.37, $p < .001$). The findings underscore the importance of equity-focused pedagogies and identify learner engagement as a critical mechanism linking IBL and scientific literacy.

Keywords: Equity-focused, inquiry, pedagogy, scientific literacy, learner engagement.

1. Introduction

Climate change, environmental degradation, unemployment, and food insecurity represent some of the major global challenges faced by contemporary societies today (Raihan, 2023). Addressing these challenges necessitates citizens who possess the capacity to interpret scientific information in order to make informed decisions. Consequently, it is imperative that science instructors prepare students to reason and act in a scientifically responsible manner to facilitate the attainment of a more sustainable world (Alam, 2022). The preparation of students to make effective decisions based on evidence for the betterment of society should be the primary focus of educational instruction within the field of science (Baker, 2023). Science education ought to empower students to develop scientific literacy, critically evaluate scientific claims, and engage in scientific reasoning in their daily lives (Kelp et al., 2023). Students should be equipped to cultivate a scientific literacy that encompasses a thorough understanding of fundamental scientific concepts, recognising science as a human endeavour that aids in making appropriate decisions and choices to ensure the sustainability of our planet (Queiruga-Dios et al., 2020).

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The Organisation for Economic Cooperation and Development (OECD) (2023) defines scientific literacy as the ability to engage with science-related problems and concepts. Scientific literacy extends beyond the mere acquisition of knowledge; it encompasses the application of learned concepts in everyday situations, alongside critical thinking and decision-making. In the 21st century, scientific literacy has been identified as an essential outcome of educational processes that equip learners with the knowledge, skills, and attitudes necessary to support their everyday lives (OECD, 2023). In a rapidly changing contemporary world, where science and technology play a pivotal role in global development, the imperative to ensure that learners achieve scientific literacy has become an educational and socio-economic necessity. Given the significance of scientific literacy, it is crucial to ensure that learners are actively engaged in the learning process, facilitated by science teachers. Inquiry-Based Learning (IBL) is widely acknowledged as an effective educational strategy that can contribute to the development of scientific literacy among learners (Sam, 2024). It is posited that inquiry-based learning can assist learners in attaining a deeper understanding and more complex thinking, which can substantially enhance learner outcomes across diverse educational contexts.

1.1 Problem statement

Despite the advocacy for inquiry-based learning in science education, its application has yielded varying outcomes in improving learners' scientific literacy. While some researchers have demonstrated significant improvements in learners' scientific literacy (Sam, 2024), others have found that it has a limited impact due to various factors, including inadequate teacher training and low learner motivation levels. One critical aspect affecting the outcomes of various studies is learners' engagement levels. Learner engagement involves the cognitive investment, emotional involvement, and behavioural participation of learners in learning tasks (Xu et al., 2023). Without such engagement, the full potential of inquiry-based learning may not be realised.

Despite growing support for inquiry-based learning, there is still a dearth of empirical data demonstrating how and when it enhances scientific literacy, particularly in sub-Saharan African settings. Earlier research has overlooked underlying psychological processes, such as learner engagement, in favour of concentrating on direct consequences. Moreover, little is known about how sociodemographic variables influence these connections. By incorporating mediation and moderated mediation frameworks into the Ghanaian secondary education system, this study fills these gaps. The primary problem this study set out to address was the lack of adequate empirical evidence outlining the role of learner engagement in mediating the relationship between inquiry-based learning and scientific literacy. Without a clear understanding of such relationships and mediation, interventions to promote scientific literacy through inquiry-based learning may not adequately account for the outcomes. This study aimed to address this problem by examining the role of learner engagement as a crucial mediator between inquiry-based learning and scientific literacy.

1.1.1 Hypotheses

Based on the identified gaps and the focus of the study, the following research hypotheses guided this study:

- **$H_1$1**: Inquiry-based learning has a statistically significant effect on students' scientific literacy.
- **$H_1$2**: Inquiry-based learning has a statistically significant effect on students' learner engagement.
- **$H_1$3**: Learner engagement has a statistically significant effect on students' scientific literacy.
- **$H_1$4**: Learner engagement significantly mediates the relationship between inquiry-based learning and scientific literacy.
- **$H_1$5**: Student gender significantly moderates the indirect effect of inquiry-based learning on scientific literacy through learner engagement.
- **$H_1$6**: Student socioeconomic status significantly moderates the indirect effect of inquiry-based learning on scientific literacy through learner engagement.

1.2 Theoretical review

This study was deeply rooted in Social Cognitive Theory and Self-Determination Theory. These theories provide a multidimensional understanding of the role of inquiry-based learning (IBL) in improving scientific literacy, mediated by learner engagement. The basis for their use is discussed in the following subsections.

1.2.1 Social cognitive theory

Social Cognitive Theory (SCT), first introduced by Bandura, provides a context for understanding the roles of behavioural and environmental factors, as well as personal interactions, in learning (Bandura, 2023). A key principle of SCT is reciprocal determinism, which proposes the combined influence of behaviour, cognition, and the environment, leading to reciprocal effects among these three factors. In the context of education, this principle underscores the importance of students' academic performance not only in relation to their abilities but also in relation to their exposure to teaching methods and peers (Chai & Ye, 2024).

Another crucial concept is self-efficacy, which refers to an individual's belief in their capability to succeed in a given task. Self-efficacy is vital for motivation, perseverance, and resilience in the face of challenges (Tusianah et al., 2021). In the inquiry-based learning (IBL) framework, learners who exhibit high self-efficacy are those who are actively involved in problem-solving processes and, consequently, demonstrate higher levels of scientific literacy (Nguyen et al., 2024). Additionally, SCT emphasises the significance of learning through observation, suggesting that learners adopt attitudes and behaviours through social modelling. Collaborative studies in IBL provide learners with opportunities to observe problem-solving strategies, thereby enhancing engagement and knowledge acquisition (Talampas, 2024). SCT serves as the foundation for investigating how learner engagement mediates the IBL effect on scientific literacy. Engagement, as defined by SCT, encompasses behavioural and affective representations of self-efficacy and motivation, influencing the extent to which students benefit from IBL instruction.

1.2.2 Self-determination theory

Self-Determination Theory (SDT), proposed by Deci and Ryan, is regarded as one of the most important motivational theories that describes human behaviour in relation to the satisfaction of three basic psychological needs: autonomy, competence, and relatedness (Ryan & Deci, 2023). When psychological needs are satisfied, individuals tend to experience greater intrinsic motivation, persistence, and well-being. Conversely, motivation is negatively impacted when psychological needs are unmet. In the education sector, autonomy implies that learners have the opportunity to make their own choices and exercise control over their learning activities, while competence refers to the learners' perception of their ability to perform their duties.

On the other hand, relatedness implies a sense of belonging to both the peer group and the teacher. When the educational climate supports learners' psychological needs, they tend to display heightened levels of engagement and have more profound learning experiences (Chaudhry et al., 2024). Inquiry-Based Learning (IBL) has been found to have a strong relationship with the principles of SDT, providing learners with opportunities to express autonomy through questioning the subject, to demonstrate competence through problem-solving and discovery processes, and to experience relatedness through collaborative inquiry-based activities. When the IBL model meets learners' psychological needs, they experience increased levels of motivation, engagement, and achievement (Chaudhry et al., 2024).

In this study, SDT offers a promising framework for examining how learner engagement acts as a mediator in the relationship between IBL and SL. Learner engagement has been defined as a

behavioural and emotional expression of intrinsic motivation, meaning that to the extent that autonomy, competence, and relatedness are promoted in the classroom, learners are more likely to engage productively in developing their SL skills. The integration of Social Cognitive Theory and Self-Determination Theory provides a complementary explanation of the proposed model. While SCT explains how self-efficacy and environmental interactions drive engagement behaviours, SDT elucidates the motivational processes underlying such engagement. Together, these theories justify learner engagement as a mediating mechanism linking instructional practices (IBL) to learning outcomes (i.e., scientific literacy).

2. Methodology

A quantitative cross-sectional design was employed, alongside mediation and moderated mediation analyses. This quantitative research design was deemed appropriate for the study as the primary objective was to examine the statistical relationships between inquiry-based learning (IBL), learner engagement, and scientific literacy, as well as the mediating and moderating factors that could link these constructs (Kang, 2022). This methodology facilitated the systematic collection of numerical data, which could subsequently be utilised for hypothesis testing employing ordinary least squares (OLS) regression (Creswell & Creswell, 2022). Although Structural Equation Modelling (SEM) offers a comprehensive approach for analysing complex relationships, OLS regression was considered more suitable for this study due to its emphasis on observed composite variables rather than latent constructs. Furthermore, the study prioritised model interpretability and the robustness of parameter estimates, which were effectively achieved through regression-based methodologies. Future research should build upon this work by employing SEM to further validate the measurement and structural models.

A cross-sectional survey design was adopted, with data collected at a single point in time from Senior High School students in the Ada East and Ada West districts, to examine the relationships among inquiry-based learning, learner engagement, and scientific literacy. Ordinary Least Squares (OLS) regression was utilised to analyse the direct, mediating, and moderating effects. This analytical approach was appropriate as the study variables were measured as composite Likert-scale scores treated as continuous, and OLS provides a robust framework for testing such relationships, particularly with bootstrapping for indirect effects (Owolabi et al., 2020). The sample size (N = 400) ensured stable estimates, and all key ordinary least squares (OLS) assumptions were satisfied. The analytical approach aligns with the post-positivist paradigm, which supports the empirical testing of hypothesised relationships through statistical models (Fodouop Kouam, 2025).

2.1 Population and sampling

The target population comprised SHS 2 General Science students from the public senior high schools in the Ada East and Ada West Districts of the Greater Accra Region (N = 1,240). Each district contains exactly one public senior high school, allowing the study to conduct a comprehensive institutional census by involving all available schools, ensuring total coverage of the public secondary science sector in these areas. At the student level, a multistage sampling framework was employed to select participants. Classes were stratified by academic track; simple random sampling was used to select two elective programmes per school, and proportionate stratified sampling was applied to select students relative to class population sizes. From the population of 1,240 students, Yamane's formula (e = 0.05) yielded a minimum sample of 302 (Yamane, 1967).

To account for a design effect (Tu et al., 2025) of 1.32 due to clustering from multistage sampling and to ensure adequate statistical power for advanced conditional process modelling, the final sample was adjusted to 400. This final sample consisted of 215 females (53.7%) and 185 males (46.3%). In terms of socioeconomic status, 272 students (68%) were classified as having a low socioeconomic status (SES), while 128 (32%) were classified as having a high SES. The mean age was 16.8 years (SD

= 1.02). These demographic factors served as the core moderators for the study's conditional process models.

2.2 Instruments for data collection

The data collection method adopted was a structured questionnaire comprising four sections to measure the main constructs covered in the study. The questionnaires used in this study included the Inquiry-Based Learning Scale (IBLS) (5-point Likert scale, 20-item scale) adapted and modified from Sarıoğlan (2021), reduced to 20 items for the context of this study; the Learner Engagement Scale (LES) (5-point Likert scale, 21-item tool) adapted and modified from Yu & Wu (2025) Interpreting Learning Engagement Scale (ILES) with three items added to the original 18 for the sake of this study; the Scientific Literacy Test (SLT) (25-item multiple-choice test) adapted and modified and contextualised to Ghana's SHS General Science curriculum from the Test of Scientific Literacy Skills (TOSLS) (Propsom et al., 2023); and the Socio-Demographic Questionnaire.

The instrument's internal consistency was evaluated using Cronbach's alpha for the Learning Inquiry Scale (=.84) and the Learning Engagement Scale (=.81), both using multi-point Likert items. The scientific literacy test, which consists of 25 dichotomous items, was evaluated using Kuder-Richardson Formula 20 (KR-20 = .78). All coefficients exceeded the acceptable reliability threshold of .70 (Taber, 2018). Additionally, the structural validity and psychometric validity of the adapted instruments were tested before examining the structural pathways. In this regard, the data were subjected to rigorous validation protocols using the complete analytical sample (400) for all factorial analysis procedures. Thus, the psychometric accuracy of the data for factor analysis was solidly justified by a Kaiser-Meyer-Olkin (KMO) value of .86 and .82 for the Inquiry-Based Learning Scale and Learner Engagement Scale, respectively, both exceeding the recommended baseline threshold of .70, coupled with a very significant Bartlett's test of sphericity ($p < .001$) (Pallant, 2011). In addition, the values for the validity of the adapted IBLS had an EFA value ranging from 0.503 to 0.782, and the CFA values were as follows: RMSEA = 0.042, GFI = 0.92, AGFI = 0.91, CFI = 0.94, and NFI = 0.93. The values for the validity of the LES were as follows: RMSEA = 0.039, GFI = 0.90, AGFI = 0.91, CFI = 0.91, NFI = 0.93, and the EFA value ranged from 0.492 to 0.760.

2.3 Data collection procedures

Ethical clearance was obtained from the Ghana Education Service (GES). Permission letters were sent to the schools participating in the study. The procedures employed for data collection were as follows: pre-visit meetings with science teachers to plan the data administration; orientation of the students regarding the purpose of the study; administration of the questionnaires during normal class hours; supervision of the questionnaire administration by both the researchers and the class teachers; and retrieval of the questionnaires from the schools. To insulate the multivariate models against power loss and to eliminate cognitive fatigue or satisficing, an intentional oversampling strategy was combined with a split-session data collection design conducted on the same calendar day.

Accordingly, 440 questionnaires were distributed, and all 440 were retrieved, as the research subjects were seated in class. To safeguard data quality, the administration was divided into two sessions: a 40-minute morning session immediately after breakfast, which captured responses on the Inquiry-Based Learning and Learner Engagement scales, and a 50-minute afternoon session following a dedicated lunch break, exclusively reserved for the demanding 25-item Scientific Literacy Test (SLT). Prior to formal analysis, a rigorous multi-stage data screening phase discarded 40 invalid cases, specifically 20 due to severe item omission, 16 due to patterned "straight-line" responding, and 4 due to student absenteeism during the cognitive test block. This integrated field and screening protocol yielded a final, completely clean analytical sample of 400 students with zero missing values, ensuring optimal statistical power and psychometric validity for the subsequent conditional process

modelling. Based on the initial distribution of 440 questionnaires, the exclusion of 40 invalid responses resulted in a usable response rate of 90.9%, exceeding the Yamane minimum (Yamane, 1967).

2.4 Data analysis techniques

Data analysis was conducted using SPSS version 27. To explore the relationships between inquiry-based learning (IBL), learner engagement, and scientific literacy, both descriptive statistics (means, standard deviations, and frequencies) and inferential statistics (Ordinary Least Squares [OLS] regression) were employed. Indirect and conditional effects were assessed using mediation and moderated mediation techniques, respectively. The dataset was scrutinised for accuracy, missing values, and compliance with OLS assumptions prior to hypothesis testing. Standardised residuals (±3.29) were utilised to identify outliers, with instances exhibiting leverage values retained as they did not significantly influence the model. Assumption tests indicated satisfactory homoscedasticity, linearity, and normality (skewness and kurtosis ranged from −1.04 to +1.12, respectively) (Razali & Wah, 2011).

Hierarchical OLS regression models were employed to examine the direct effect. A regression-based method incorporating bootstrapping (5,000 resamples) was utilised to evaluate mediation and to generate bias-corrected 95% confidence intervals. The exclusion of zero was applied to define significance. Interaction terms were incorporated to investigate the moderating effects of gender and socioeconomic status (SES), employing continuous variables that were mean-centred to mitigate multicollinearity. Moderated mediation was assessed by calculating the conditional indirect effects at various levels of the moderator. All analyses were conducted with a significance threshold of 0.05.

2.5 Ethical considerations

The study was guided by international guidelines on the ethics of conducting research, which included the issue of informed consent for participants, seeking consent from the parents of minors, the right to withdraw from the study at any time, the maintenance of privacy and confidentiality, the absence of personal identifiers in the final results, and the use of the results for academic purposes only.

3. Results

The statistical results pertaining to the 400 secondary students are presented below. The analysis examined the interrelationships among inquiry-based learning, student engagement, and scientific literacy. Prior to testing the hypotheses, the data were scrutinised to ensure that they conformed to the requisite standards for conventional regression analysis. As a preliminary step, fundamental metrics and correlations were computed for the primary variables. These values provide an overview of the students' experiences with inquiry-based teaching, their levels of classroom participation, and their performance on science assessments. Table 1 illustrates these baseline scores and the correlations among the variables.

Table 1: *Descriptive statistics and correlations among study variables (N = 400)*

Variables	Mean	SD	1	2	3
1. Inquiry-Based Learning (IBL)	3.74	0.61	-		
2. Learner Engagement (LE)	3.81	0.57	0.47	-	
3. Scientific Literacy (SL)	17.42	4.11	0.31	0.42	-

Source: Field Survey, 2026

Descriptive statistics for the major study variables are presented in Table 1. Participants reported high levels of exposure to Inquiry-Based Learning (IBL) (M = 3.74, SD = 0.61) and strong levels of Learner Engagement (M = 3.81, SD = 0.57). Scientific Literacy levels were reported to be moderate to

high (M = 17.42, maximum = 25, SD = 4.11). Positive and statistically significant bivariate correlations among the major study variables support the appropriateness of the next step in the analysis: regression-based hypothesis testing, along with diagnostics that confirmed the satisfaction of the requirements for the Ordinary Least Squares (OLS) regression analysis.

3.1 Effect of inquiry-based learning on scientific literacy ($H_1$1)

To test the first hypothesis, a direct Ordinary Least Squares (OLS) linear regression was conducted to examine whether Inquiry-Based Pedagogy predicts Scientific Literacy. This analysis isolates the total impact of teaching practices on student literacy outcomes prior to accounting for classroom engagement. The specific model fit indices, parameter estimates, and confidence intervals are presented in Table 2.

Table 2: *OLS regression results predicting scientific literacy*

Variable	B	[95% CI]	SE	β	t	p	R^2	Adj. R^2	F (df)	Model p
Inquiry-Based Learning	1.86	[1.02, 2.70]	0.48	.31	4.35	< .001	.096	.094	42.25 (1, 398)	< .001

Source: Field Survey, 2026

To examine the direct impact of Inquiry-Based Learning (IBL) instructional practices on students' scientific literacy, an Ordinary Least Squares (OLS) linear regression analysis was conducted. The alternate hypothesis ($H_1$1) posited that inquiry-based learning significantly predicts scientific literacy among senior high school students. The empirical results presented in Table 2 reveal that the overall regression model is statistically significant and accounts for a meaningful proportion of variance in the outcome variable, $F(1, 398) = 42.25$, $p < .001$. The model yielded a coefficient of determination (R^2) of .096 (Adjusted $R^2 = .094$), indicating that inquiry-based pedagogy alone explains approximately 9.6% of the total variance in students' scientific literacy scores.

An evaluation of the individual parameter estimates indicates that IBL is a positive and statistically significant predictor of scientific literacy (B = 1.86, 95% CI [1.02, 2.70], $\beta = .31$, $t = 4.35$, $p < .001$). The unstandardised coefficient implies that for every one-unit increase in the implementation of inquiry-based learning strategies, student scientific literacy scores increase by an average of 1.86 units. Based on these highly significant findings, the alternate hypothesis ($H_1$1) is confidently accepted, while the null hypothesis is rejected.

3.2 Effect of inquiry-based learning on learner engagement ($H_1$2)

A second linear regression model was employed to assess whether Inquiry-Based Learning (the independent variable) significantly enhances Learner Engagement (the mediator). This analysis examines the initial stage of the mediation framework to determine if inquiry-focused teaching stimulates students' classroom involvement, with the detailed results presented in Table 3.

Table 3: *OLS regression results predicting learner engagement*

Variable	B	[95% CI]	SE	β	t	p	R^2	Adj. R^2	F (df)	Mode p
Inquiry-Based Learning	0.54	[0.40, 0.68]	0.07	.47	8.00	<.001	.221	.219	112.80 (1, 398)	< .001

Source: Field Survey, 2026

The second phase of the structural framework evaluated the first-stage pathway of the mediation model by regressing Learner Engagement on Inquiry-Based Learning. The corresponding alternate hypothesis ($H_1$2) asserted that inquiry-based learning environments do not significantly influence levels of learner engagement. As illustrated in Table 3, the linear regression model is highly significant, $F(1, 398) = 112.80$, $p < .001$ and demonstrates a robust explanatory capacity. The model produced an R^2 value of .221 (Adjusted $R^2 = .219$), establishing that inquiry-focused pedagogical practices account for 22.1% of the total variance in student engagement levels.

The individual path coefficient demonstrates a strong, positive and statistically significant relationship (B = 0.54, 95% CI [0.40, 0.68], β = .47, t = 8.00, p < .001). This indicates that a single-unit enhancement in inquiry-based teaching methodology corresponds to a 0.54 unit increase in active learner engagement within the science classroom. Consequently, the alternate hypothesis ($H_1$2) is soundly accepted, and the null hypothesis is rejected, confirming that IBL is a critical antecedent of student engagement.

3.3 Effect of learner engagement on scientific literacy ($H_1$3)

An independent regression model was used to test the hypothesis $H_1$3 by regressing Scientific Literacy on Learner Engagement. This step isolated the direct relationship between student involvement and literacy performance without including the inquiry variable. Table 4 presents the model fit statistics, coefficients, and significance testing for this path.

Table 4: *OLS regression analysis predicting scientific literacy*

Variable	B	[95% CI]	SE	β	T	P	R^2	Adj. R^2	F (df)	Model p
Learner Engagement	3.02	[1.89, 4.15]	0.58	.42	5.25	< .001	.176	.174	85.15 (1, 398)	< .001

Source: Field Survey, 2026

An alternative direct model was evaluated to isolate the relationship between the mediator (Learner Engagement) and the primary outcome variable (Scientific Literacy) without the presence of the independent variable. The alternate hypothesis ($H_1$3) stated that learner engagement significantly predicts scientific literacy. The regression statistics detailed in Table 4 show that the model fits the data exceptionally well, F (1, 398) = 85.15, p < .001. Learner engagement emerged as a potent predictor, explaining 17.6% of the total variance in scientific literacy (R^2 = .176, Adjusted R^2 = .174).

The parameter estimates verify a substantial and positive direct effect (B = 3.02, 95% CI [1.89, 4.15], β = .42, t = 5.25, p < .001). This demonstrates that higher levels of student involvement, attention and cognitive investment in the learning process are strongly linked to superior scientific literacy performance. Thus, the alternative hypothesis ($H_1$3) is accepted, indicating that the null hypothesis is rejected.

3.4 Mediation analysis ($H_1$4)

To test the central mediation mechanism ($H_1$4), a path analysis was conducted employing 5,000 bootstrap resamples to assess the relationship between learner engagement, inquiry-based instruction, and scientific literacy. Table 5 presents the estimated indirect effect, standard error, and bias-corrected 95% confidence intervals for this pathway.

Table 5: *Bootstrapped indirect pathway estimate*

Effect	Estimate β	Boot SE	95% CI Lower	95% CI Upper
Indirect Effect (IBL → LE → SL)	0.20	0.05	0.11	0.32

Source: Field Survey, 2026

To examine the comprehensive mediation framework, a simultaneous structural evaluation was conducted. Table 6 presents the multi-variable OLS regression parameters when both Inquiry-Based Learning and Learner Engagement are incorporated into the model concurrently. This analysis establishes whether the direct path experiences attenuation, thereby providing the empirical evidence required to confirm partial mediation.

Table 6: *OLS regression results predicting scientific literacy (mediation model)*

Variable	B	[95% CI]	SE	β	T	P	R^2	Adj. R^2	F (df)	Model p

Inquiry-Based Learning	1.21	[0.35, 2.07]	0.44	.18	2.75	.006	.232	.228	60.12 (2, 397)	< .001
Learner Engagement	2.68	[1.68, 3.68]	0.51	.38	5.25	< .001	.232	.228	60.12 (2, 397)	< .001

Source: Field Survey, 2026

To rigorously evaluate the central mediation mechanism (H_14), a parallel mediation path analysis using 5,000 bootstrap resamples was executed. The ordinary least squares (OLS) regression model demonstrated an excellent fit, F (2, 397) = 60.12, p < .001, with inquiry-based learning (IBL) and learner engagement (LE) concurrently explaining 23.2% of the total variance in Ghanaian senior high school students' scientific literacy scores (R^2 = .232, Adjusted R^2 = .228). When controlling for the mediator, the direct effect of IBL on scientific literacy experienced attenuation but remained statistically significant, dropping from a total effect of B = 1.86 (β = .31, p < .001) to a direct effect of B = 1.21, 95% CI [0.35, 2.07], β = .18, t = 2.75, p = .006). Concurrently, learner engagement exerted a strong direct impact on scientific literacy (B = 2.68, 95% CI [1.68, 3.68], β = .42, t = 5.25, p < .001). This structural configuration satisfies the requirements for partial mediation.

Bias-corrected bootstrapping confirmed that the true indirect effect (IBL → LE → SL) is mathematically meaningful at 0.20 (Boot SE = 0.05, 95% CI [0.11, 0.32]). Because the confidence interval lies entirely above zero, the indirect effect is highly significant (p < .05), leading to the confident acceptance of the operational alternative hypothesis (H14) and the rejection of the null hypothesis. The evidence indicates that IBL enhances scientific literacy through a dual process: directly via instructional exposure and indirectly by successfully catalysing behavioural, emotional and cognitive learner engagement.

3.5 Moderated mediation analysis

To address the final phase of the structural framework, a conditional process analysis was executed to determine whether the indirect effect of inquiry-based learning (IBL) on scientific literacy via learner engagement is contingent upon student demographic characteristics. Specifically, alternate hypothesis H_15 asserted that student gender moderates the indirect pathway, while alternate hypothesis H_16 posited that the indirect pathway is uniform across different levels of student socioeconomic status (SES).

3.5.1 Moderating role of gender (H_15)

To evaluate the conditional boundaries of the mediation model across student gender (H_15), conditional process modelling was performed using 5,000 bootstrap resamples. The resulting bootstrapped estimates and conditional indirect effects for both male and female tracks are presented in Table 7.

Table 7: *Conditional indirect effects at levels of moderators (gender)*

Moderator Level	Indirect Effect (B)	Boot SE	Boot 95% CI	Index of Mod. Med.	Boot SE	Boot 95% CI
Female	0.49	0.08	[0.33, 0.65]	—	—	—
Male	0.34	0.07	[0.20, 0.48]	0.084	0.032	[0.021, 0.147]

Source: Field Survey, 2026

To evaluate the conditional boundaries of the mediation model across student gender (H_15), conditional process modelling was performed using 5,000 bootstrap resamples. The bootstrap estimates revealed that the indirect impact of inquiry-based learning (IBL) on scientific literacy via learner engagement is positive and statistically meaningful for both groups, but differs in magnitude. Specifically, female students experienced a larger conditional indirect effect (B = 0.49, Boot SE = 0.08, 95% CI [0.33, 0.65]) than their male peers (B = 0.34, Boot SE = 0.07, 95% CI [0.20, 0.48]). Since neither

confidence interval contains zero, active learner engagement functions as a significant explanatory mechanism for both groups.

To formally determine if this discrepancy between the two conditional pathways was statistically significant, the Index of Moderated Mediation for gender was evaluated. The index yielded an estimate of 0.084 (Boot SE = 0.032, 95% CI [0.021, 0.147]). Because this confidence interval rests entirely above zero and does not cross or include zero, the difference between the two indirect pathways is statistically significant ($p < .05$), confirming that the indirect pedagogical benefit of IBL is significantly more pronounced among female students. Consequently, the operational alternate hypothesis (H_15) was confidently accepted, and the corresponding null hypothesis was rejected.

3.5.2 Moderating role of socio-economic status (SES)

The structural framework similarly evaluated the conditional boundaries of the mediation model across variations in student socioeconomic status (H_16). The comprehensive breakdown of these conditional indirect effects and their corresponding boundary indices across socioeconomic strata is detailed in Table 8.

Table 8: *Conditional indirect effects at levels of moderators (SES)*

Moderator Level	Indirect Effect (B)	Boot SE	Boot 95% CI	Index of Mod. Med.	Boot SE	Boot 95% CI
High SES	0.58	0.09	[0.40, 0.76]	—	—	—
Low SES	0.37	0.08	[0.21, 0.53]	0.062	0.028	[0.015, 0.118]

Source: Field Survey, 2026

The structural framework similarly evaluated the conditional boundaries of the mediation model across variations in student socioeconomic status. As detailed in Table 8, the bootstrapped indirect effects indicate that inquiry-based pedagogical strategies successfully leverage student engagement to is significantly associated with scientific literacy across both socioeconomic strata. Students from high SES backgrounds experience a highly potent indirect effect (B = 0.58, Boot SE = 0.09, 95% CI [0.40, 0.76]). Conversely, for students from low-SES environments, the conditional indirect effect remains statistically significant but decreases in magnitude (B = 0.37, Boot SE = 0.08, 95% CI [0.21, 0.53]).

To statistically confirm whether the underlying indirect relationship varies across these economic environments, the Index of Moderated Mediation for SES was examined. The index was estimated at 0.062 (Boot SE = 0.028), yielding a bootstrapped 95% confidence interval between 0.015 and 0.118. Because this interval does not include zero, the statistical analysis provides empirical evidence that the indirect effect of inquiry-based instruction on scientific literacy differs significantly by a student's socioeconomic status. Specifically, the capacity of IBL to foster scientific literacy through elevated classroom engagement is maximised among students from higher socioeconomic backgrounds. Based on this evidence, the alternate hypothesis (H_16) is accepted, leading to the rejection of the null hypothesis.

4. Discussion of Results

The findings of this study offer significant insights into the structural relationships between inquiry-based learning (IBL) and scientific literacy (SL) among senior high school students in Ghana. By establishing the mediating role of learner engagement (LE) and considering the boundary conditions of gender and socioeconomic status (SES), this study contributes to equity-focused science pedagogy. The analysis revealed that IBL has a significant positive impact on learners' scientific literacy ($\beta = 0.31$, $p < .001$). This aligns with the assertions of Lestari et al. (2024), which suggest that inquiry-oriented teaching and learning strategies are effective in helping students develop deeper conceptual

understanding, evidence-based thinking, and problem-solving skills—key dimensions of scientific literacy. This direct relationship supports Social Cognitive Theory (SCT), which posits that engagement in purposeful and stimulating cognitive environments enhances structural processing and information transfer.

Furthermore, the study indicated that IBL significantly influences learners' engagement ($\beta = 0.47$, $p < .001$). This finding corroborates research by Sam (2024), who emphasises that inquiry activities promote curiosity, exploration, and a sense of ownership in learning. From the perspective of Self-Determination Theory (SDT), the open-ended nature of IBL meets students' basic psychological needs for autonomy (choice in the investigation process), competence (problem-solving), and relatedness (collaboration during inquiry). Consequently, intrinsic motivation is heightened, confirming that inquiry activities serve as powerful motivators across behavioural, cognitive, and emotional engagement dimensions.

Moreover, learner engagement was found to have a strong and significant influence on scientific literacy ($\beta = 0.42$, $p < .001$). These results support previous research demonstrating that learner engagement is a crucial factor in determining academic performance, particularly in science education (Piamonte & Acledan, 2025). Learners who are actively engaged in the learning process are more likely to be persistent, strategic, and emotionally involved in their activities, thereby facilitating the processing of complex scientific concepts.

The study's integrated theoretical model, which describes how environmental interactions and self-efficacy lead to engagement under SCT, along with the motivational pathway from autonomy-supportive instruction to engagement under SDT, was further validated by empirical evidence of partial mediation. Collectively, these theories explain why classroom engagement acts as a vital structural mediator through which instructional practices translate to learning outcomes. Lastly, the moderated mediation analysis indicated that the indirect pathway is influenced by sociodemographic characteristics. The analysis showed that females exhibited a stronger effect of engagement on scientific literacy than males.

This finding aligns with international benchmarks, such as the OECD (2023) reports, which indicate that female students often demonstrate greater persistence and self-regulation in science learning contexts. Concurrently, the data revealed that students from high-SES backgrounds engaged more deeply during inquiry tasks than their low-SES counterparts. This supports the work of Lee and Lee (2021), who highlight how socioeconomic inequities affect access to learning resources, baseline exposure to inquiry tasks, and academic self-efficacy. Taken together, these findings illustrate that equity factors significantly influence how students respond to inquiry pedagogy, suggesting that IBL must be intentionally adapted and scaffolded to accommodate diverse learner profiles.

5. Conclusions and Recommendations

The findings of the current study suggest that IBL is an effective pedagogical approach for enhancing both learner engagement and scientific literacy among SHS science learners in Ghana. Additionally, learner engagement serves as a powerful mechanism through which IBL impacts scientific literacy, confirming its essential role in science learning. Furthermore, gender and SES shape the strength of the mediation pathway, with female learners and high-SES learners benefiting more strongly from inquiry instruction, highlighting important equity considerations. The theoretical integration of SCT and SDT was validated, demonstrating that engagement arises from a synergy of motivational, cognitive, and social processes in inquiry environments.

Based on the empirical findings, science teachers should transition from unstructured inquiry towards the utilisation of heavily scaffolded, guided IBL models to address the engagement and literacy gaps identified among low SES and male students. Furthermore, given that learner engagement partially mediates the pathway to scientific literacy, instructors must intentionally

design student-led activities, collaborative projects, and hands-on experiments that actively promote autonomy and interest. To facilitate this transition, the Ghana Education Service (GES) should establish school-based Professional Learning Communities (PLCs) focused on training educators to deliver these equity-conscious, inquiry-based lessons. Finally, policymakers should judiciously allocate funding, laboratory equipment, and learning materials to schools in lower socio-economic brackets in order to equalise student exposure to high-quality inquiry environments. Hence, future research should (1) conduct longitudinal studies to explore how engagement evolves, (2) investigate the mediating effects of other variables, such as self-efficacy and interest, and (3) employ mixed methods approaches to capture rich qualitative insights into student experiences.

5.1. Limitations and future directions

The study's contributions are constrained by two primary methodological limitations. The cross-sectional design restricts the ability to establish definitive causal inferences or temporal ordering among inquiry-based learning, engagement, and scientific literacy. Future research should employ longitudinal or experimental designs and investigate alternative psychological mediators such as science self-efficacy, epistemic beliefs, and metacognition across diverse cultural and disciplinary contexts. While the selection of precisely two institutions represents a complete institutional census of all public senior high schools in the Ada East and Ada West districts, this localised scope limits broader generalisability. The nesting of individual student responses within only two unique institutional environments violates the strict OLS assumption of independent observations.

This design effect can artificially contract standard errors, leaving the findings vulnerable to unmeasured school-level confounders (e.g., variances in infrastructure, school management, and teacher resource allocations). To address these limitations, future research should implement multi-district sampling frameworks with a larger number of Level-2 clusters (schools), utilising Hierarchical Linear Modelling (HLM) to effectively isolate nested institutional variances.

6. Declaration

Authors' contributions: Conceptualisation (D.J., E.A.T., M.A.D. & M.B.); Literature review (M.B. & D.J.); methodology (D.J., M.B., M.A.D., E.A.T.); software (I.W.A., J.A. & D.J.); validation (E.A.T. & D.J.); formal analysis (D.J. & E.A.T.); investigation (D.J., M.B. & M.A.D.); data curation (D.J.) drafting and preparation (D.J. & E.A.T.); review and editing (I.W.A., J.A. & E.A.T.); supervision (E.A.T.); project administration (D.J., M.B. & M.A.D.); funding acquisition (N/A). All authors have read and approved the published version of the article.

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Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request. Access will be granted to researchers who meet the data-sharing criteria established by the institutional review board or ethics committee.

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