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Technology-enhanced Inquiry-based Learning for Sustainable Science Education: Equity, Attitudes, and Achievement in Nigerian Junior Secondary Schools: A Quasi-experimental Study

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Abstract

This study examined whether a Technology-Enhanced Inquiry-Based Learning Educational Package (TIBLEP) can promote sustainable and equitable science education by improving junior secondary students' attitudes toward Natural Science and their academic achievement in Ibadan, Oyo State, Nigeria. A quasi-experimental pretest–posttest control-group design was used with 200 students from six public schools. Over ten weeks, the experimental group received TIBLEP instruction, while the control group received conventional lecture-based instruction. Attitudes and achievement were assessed using the Natural Science Attitudinal Scale (NSATS; $\alpha = 0.73$) and the Natural Science Achievement Scale (NSAS; KR-20 = 0.73). Wilcoxon signed-rank analysis showed a significant improvement in attitudes following TIBLEP ($z = -8.62$, $p < 0.001$). ANCOVA also indicated a large and significant treatment effect on achievement, $F(1, 195) = 756.00$, $p < 0.001$, partial $\eta^2 = 0.795$. Socio-economic background moderated attitudinal outcomes, with higher-SEB students reporting more favorable attitudes, but had no significant effect on achievement. Gender differences were negligible for both outcomes. The findings demonstrate that offline, technology-enhanced inquiry can support effective and equitable science learning in resource-constrained settings. TIBLEP offers a scalable approach to sustainable science education by addressing infrastructural limitations while reducing disparities in learning outcomes. Implications for curriculum integration, teacher professional development, equitable resource allocation, and formative assessment reform are highlighted.

1. Introduction

The push for sustainable development has placed quality, equitable education at the center of global policy, most visibly through Sustainable Development Goal 4, which calls for inclusive learning opportunities that leave no learner behind (Zickafoose et al., 2024; UNESCO, 2023). Science education sits squarely within this agenda: it is where problem-solving, critical thinking, and adaptability, the competencies a knowledge-driven, sustainability-conscious economy demands, are meant to be developed. Yet in much of the twenty-first century, science classrooms remain wedded to teacher-centered, rote-memorization practices that struggle to cultivate these competencies (Allayarova, 2025; Heleta & Bagus, 2021). This gap between what science education is meant to achieve and what it currently delivers is especially visible in resource-constrained contexts, where the tools for a more active, sustainable pedagogy are hardest to obtain.

Inquiry-Based Learning (IBL) has emerged as a pedagogical response to this gap, positioning learners as active investigators who construct knowledge through questioning, exploration, and problem-solving rather than passively receiving it (Moris, 2025). Meta-analytic evidence supports this shift: Furtak et al. (2012) found that experimental and quasi-experimental IBL interventions produced meaningful gains in both cognitive and affective outcomes, and Uluçınar (2023), synthesizing 55 studies, reported a high overall effect of problem-based and inquiry-oriented approaches on science achievement relative to traditional instruction. Yet translating this evidence into resource-constrained classrooms is not

automatic. In Nigeria, large class sizes, inconsistent infrastructure, and limited teacher preparation continue to limit the extent of genuine inquiry students experience (Şengül & Karabacak, 2026).

Comparative work underscores both the promise and the difficulty of this transfer. Freeman et al. (2014), drawing on 225 studies across Science, Technology, Engineering and Mathematics (STEM) disciplines, showed that active-learning strategies consistently outperform lecture-only instruction, reducing failure rates and strengthening conceptual understanding. A systematic review by Chen and Chen (2024) of technology-enhanced collaborative inquiry in K–12 classrooms similarly found that technological tools raise engagement and support novice learners, but only when paired with deliberate activity structures; several of the reviewed studies documented inquiry breaking down when technology was introduced without this support. Read together, these findings suggest that technology is not a substitute for structured pedagogy; it is a delivery mechanism that succeeds or fails depending on how well it is embedded within one (Shaeffer, 2019).

Offline platforms, such as the Technology-Enhanced Inquiry-Based Learning Educational Package (TIBLEP), directly address this design requirement. By delivering inquiry-driven digital content without requiring internet connectivity, TIBLEP is built for the infrastructural realities of many Nigerian classrooms, and it does so in a way consistent with global calls for equitable, inclusive, and sustainable access to quality learning materials (UNESCO, 2023).

Evidence from South African science classrooms illustrates why this design consideration matters and why its benefits are not automatic. Dunn and Ramnarain (2025) tested mobile technology-supported abductive inquiry in chemical bonding among Grade 11 physical sciences learners and found that the technology-supported group did not outperform a no-technology control group on the core cognitive measure of generating scientifically accurate hypotheses. Yet these learners reported greater agency, stronger communication, and more engagement with the material. Lotter and Ramnarain (2025), examining a flipped-classroom model for natural sciences inquiry, likewise found that whether technology-mediated inquiry translated into deeper learning depended heavily on how teachers orchestrated consolidation and sense-making after the technology-based activity, not on the presence of the technology itself. Together, these studies indicate that instructional innovation must be context-sensitive: a strategy effective in one setting can under-deliver in another unless its cognitive and motivational demands are deliberately scaffolded. TIBLEP is designed as such an adaptation — offline, inquiry-driven, and tailored to Nigerian classroom realities.

Socioeconomic background (SEB) and gender adds further complexity. Learners from disadvantaged backgrounds often face constrained exposure to digital tools, reduced parental support, and limited learning environments (Nzuza, 2025; Rahman & Ahmed, 2025), disparities that can shape both attitudes toward science and academic performance. Kyriakides et al. (2018), reviewing the evidence on student background characteristics and achievement, found that socioeconomic disadvantage is consistently associated with weaker outcomes, while Vadivel et al. (2023) confirmed that inquiry-based learning can engage students from diverse backgrounds even as the size of its benefit remains sensitive to resource

availability and teacher facilitation. Gender differences also shape outcomes in mixed ways: Ganajová et al. (2025) reported that inquiry-based interventions lifted motivation for both genders, while Teplá and Distler (2025) found that structured inquiry helped narrow gender gaps in conceptual understanding. Tools such as TIBLEP, by offering interactive and inclusive learning experiences, may therefore hold particular promise for reducing gender disparities in participation in science.

Against this backdrop, the present study investigates whether TIBLEP improves students' attitudes toward Natural Science and their academic achievement, and, importantly, how socioeconomic background and gender intersect with technology-enhanced inquiry to shape these outcomes. By situating the analysis in a resource-limited Nigerian setting, the study speaks to the broader question of how technology can be leveraged not merely to raise achievement, but to do so sustainably and equitably — preparing students for the demands of twenty-first-century learning without widening the gaps that already divide them. The study addresses the following research questions:

Research Questions

1. What is the effect of the Technology-Enhanced Inquiry-Based Learning Package (TIBLEP) on students' attitudes toward Natural Science?

2. How does TIBLEP affect students' academic achievement in Natural Science compared with traditional teaching methods?

3. To what extent does socioeconomic background moderate the relationship between TIBLEP use and students' attitudes toward Natural Science?

4. How does socioeconomic background affect the relationship between TIBLEP use and students' academic achievement in Natural Science?

5. Are there significant gender differences in students' attitudinal disposition and academic achievement when exposed to TIBLEP?

2. Literature Review

Inquiry-Based Learning is widely recognised as a pedagogical approach that fosters critical thinking, collaboration, and problem-solving. Unlike traditional teacher-centred methods, IBL positions students as active participants in knowledge construction, encouraging them to question, explore, and engage in authentic problem-solving. Meta-analyses confirm that IBL enhances both cognitive and affective outcomes, including achievement, motivation, and attitudes toward science (Furtak et al., 2012; Uluçınar, 2023), and Freeman et al. (2014) further demonstrated, across 225 Science, Technology, Engineering and Mathematics (STEM) studies, that active-learning strategies significantly reduce failure rates and improve conceptual understanding relative to lecture-only instruction.

Technology-enhanced inquiry broadens the scope of IBL by integrating digital tools that support visualisation, simulation, and interactive engagement. Chen and Chen's (2024) systematic review of technology-enhanced collaborative inquiry in K–12 classrooms found that technological tools most reliably improved inquiry outcomes when they were paired with explicit activity strategies at each stage of the inquiry process: orientation, investigation, and consolidation, and that technological scaffolding was particularly valuable for learners with lower prior knowledge. Offline platforms such as TIBLEP are especially relevant in resource-constrained contexts because they extend this kind of structured, technology-supported inquiry without requiring internet connectivity (UNESCO, 2023).

African evidence highlights both the promise and the conditions attached to it. Dunn and Ramnarain (2025) found that Grade 11 South African learners using mobile-simulation-supported abductive inquiry did not out-perform a no-technology control group in generating scientifically accurate hypotheses, even though they reported greater agency, communication, and engagement — a reminder that motivational gains from technology-enhanced inquiry do not automatically translate into the specific cognitive skill being targeted unless the reasoning process itself is explicitly scaffolded. Lotter and Ramnarain (2025) similarly found that the success of technology-mediated inquiry in South African natural sciences classrooms depended heavily on how teachers orchestrated discussion and sense-making after the technology-based activity. These findings underscore that instructional innovation must be adapted to context: a strategy effective in one classroom may under-deliver in another unless it is tailored to local realities and paired with deliberate pedagogical structure.

Attitudes toward science are multidimensional, encompassing emotions, beliefs, and behaviours. Positive attitudes are associated with greater motivation, engagement, and achievement, whereas poor instructional practices often produce negative Ganajová et al. (2025) found that inquiry-based interventions improved motivation across genders, while Teplá and Distler (2025) found that structured inquiry narrowed gender gaps in conceptual understanding. Socioeconomic background (SEB) remains a critical factor shaping educational outcomes: Kyriakides et al. (2018), in their review of student characteristics and achievement, found that learners from higher-SEB backgrounds consistently outperform lower-SEB peers, an advantage generally attributed to differential access to learning resources. Vadivel et al. (2023) confirmed that inquiry-based learning can engage students from diverse socioeconomic backgrounds, though the size of its benefit is moderated by contextual inequalities, and Nzuza (2025) and Rahman and Ahmed (2025) similarly emphasised that learners from disadvantaged backgrounds face barriers, including limited exposure to digital tools and constrained learning environments, that can shape both attitudes and performance.

Together, these studies point to the need to examine how technology-enhanced inquiry interacts with socioeconomic background and gender to shape outcomes in resource-constrained contexts such as Nigeria, and, by extension, whether such interventions can be scaled sustainably without reproducing existing inequities.

3. Theoretical Framework

This study draws on three theoretical perspectives. First, constructivism holds that learners build knowledge more effectively through active engagement with problems than through passive reception; TIBLEP embodies this principle by positioning students as investigators who construct understanding through inquiry tasks. Second, guided inquiry theory emphasises the importance of scaffolding: Kirschner, Sweller, and Clark (2006) argued that minimally guided instruction can overwhelm novice learners, and that structured inquiry — which balances learner autonomy with instructional support — produces more reliable gains. TIBLEP's design reflects this balance by embedding inquiry-driven tasks with immediate feedback and teacher facilitation. Third, equity frameworks hold that instructional innovation must be evaluated not only for its effectiveness but also for its fairness across groups. By testing socioeconomic background and gender as moderators, this study situates technology-enhanced inquiry within the broader, sustainability-oriented debate about equitable access to quality science education.

4. Conceptual Framework

The conceptual framework illustrates the hypothesised relationships among the study's key variables. TIBLEP serves as the independent variable, expected to influence students' attitudes toward Natural Science, which in turn affect academic achievement. Attitudes therefore serve as a mediating pathway, while socioeconomic background and gender function as moderators. Exposure to inquiry-based, technology-supported learning is expected to foster positive attitudes — interest, motivation, and confidence in science — that enhance persistence, participation, and cognitive engagement, thereby leading to higher achievement. Socioeconomic background may strengthen or weaken TIBLEP's impact depending on learners' access to resources, while gender may shape confidence and engagement. This relationship is depicted in Fig. 1.

5. Methodology

This study adopted a quasi-experimental pretest/posttest control-group design. Random assignment of students to treatment and control groups was not feasible within intact classroom settings, so existing classes were designated as either experimental (TIBLEP) or control (conventional instruction). This design permitted comparison of outcomes while preserving ecological validity in real school contexts. Pretests established baseline measures of achievement and attitudes, while posttests captured the effects of the intervention.

Sampling and Sampling Technique

The target population comprised junior secondary school students in Ibadan, Oyo State, Nigeria. A multistage sampling procedure was used: the Ibadan Metropolis was stratified into two educational zones, each comprising eleven Local Government Areas (LGAs), and one LGA was randomly selected from one zone. Six co-educational public junior secondary schools were then randomly selected from that LGA, based on the availability of functional computers and electricity. From each school, one intact

Natural Science class was purposively selected, yielding a sample of 200 students (97 males, 103 females) aged 11–16 years. This sample size was considered adequate for Analysis of Covariance (ANCOVA), providing sufficient power to detect treatment effects.

Instruments

Two validated instruments were used. The Natural Science Attitudinal Scale (NSATS) is a 15-item Likert-type instrument measuring students' attitudes toward Natural Science, with a Cronbach's α reliability of 0.73. The Natural Science Achievement Scale (NSAS) is a multiple-choice test covering topics such as energy, electricity, and chemical substances, with reliability confirmed by a KR-20 of 0.73. Both instruments underwent expert review for content validity and pilot testing to ensure clarity and appropriateness.

Intervention Procedures

The intervention lasted ten weeks. In the experimental group, students used TIBLEP, an offline platform offering inquiry-driven digital lessons that supported self-paced exploration, immediate feedback, and guided problem-solving, with teachers serving as facilitators who provided support as difficulties arose. In the control group, students received conventional lecture-based instruction using textbooks and teacher explanations, with lessons emphasising note-taking and end-of-topic testing. Both groups covered identical curriculum content for equal instructional time to ensure comparability, and fidelity checks — including classroom observations and teacher logs — confirmed consistent implementation.

Data Collection Procedure

Data were collected in three stages. At pretest, both groups completed NSATS and NSAS to establish baseline measures. During the intervention, the experimental group used TIBLEP while the control group received traditional instruction. At posttest, both groups completed NSATS and NSAS again to capture change in attitudes and achievement. Teacher interviews supplemented the quantitative data, offering insight into implementation fidelity and classroom dynamics. Ethical approval was obtained, and informed consent was secured from students and parents.

Data Analysis

Data were analyzed using SPSS version 26. Descriptive statistics (frequencies, percentages, means) summarized demographic characteristics. A Wilcoxon signed-rank test assessed changes in attitudes from pretest to posttest, and ANCOVA tested differences in achievement between groups while controlling for pretest scores. ANCOVA assumptions (normality, homogeneity of variance, linearity) were evaluated using Levene's test and residual plots. Effect sizes were reported using partial eta squared (η^2), with benchmarks of 0.01 (small), 0.06 (moderate), and 0.14 (large). Significance was set at $p < 0.05$ for all analyses.

6. Results

The demographic distribution of the sample is shown in Table 1.

Table 1
Demographic Distribution by School, Gender, and Age Range

School	Gender	Frequency	Age 10–13	Age 14–17
1	Male	14	5	11
	Female	18	4	14
2	Male	14	2	14
	Female	17	4	13
3	Male	14	2	14
	Female	18	3	15
4	Male	15	6	9
	Female	20	6	12
5	Male	14	6	8
	Female	22	6	13
6	Male	10	6	8
	Female	22	6	15
Total		200	56	144

Table 1 shows that the study involved 200 junior secondary students — 97 males and 103 females, drawn from six schools, with the majority of learners falling within the 14–17 age band. This gender balance and coherent age range support the sample's suitability for examining TIBLEP's effects on attitudes and achievement in Natural Science.

RQ1: Effect of TIBLEP on Students' Attitudes Toward Natural Science

A Wilcoxon signed-rank test was conducted to determine whether students' pretest and posttest attitude scores changed following exposure to TIBLEP.

Table 2
Wilcoxon Signed-Rank Test on Students' Attitudes (Pre- and Post-Test)

Group	Negative Ranks	Positive Ranks	Ties	N	Mean Rank	Z	p
Treatment	6	94	0	100	53.50	-8.62	0.000
Control	0	85	15	100	43.00	-8.03	0.214

Table 2 shows that students in the experimental group registered a significant improvement in attitudes toward Natural Science ($z = -8.62$, $p < 0.05$), whereas the control group showed no statistically significant change. This indicates that TIBLEP had a positive effect on students' attitudinal disposition.

RQ2: Effect of TIBLEP on Students' Academic Achievement

ANCOVA was used to test the main effect of treatment on achievement while controlling for pretest scores.

Table 3
ANCOVA Summary of Students' Achievement in Natural Science by Treatment

Source	SS	df	MS	F	p	Partial η^2
Corrected Model	79,614.17	4	19,903.54	258.21	0.000	0.841
Pre-Test	2,990.94	1	2,990.94	38.80	0.000	0.166
Treatment	58,273.44	1	58,273.44	756.00	0.000	0.795
SEB	57,363.43	1	57,363.43	1.13	0.253	0.100
Gender	1.93	1	1.93	0.025	0.874	0.000
Treatment × Gender	81.12	1	81.12	1.05	0.306	0.005
Error	15,030.70	195	77.08			

Table 3 shows a highly significant main effect of treatment on achievement, $F(1, 195) = 756.00$, $p < 0.001$, partial $\eta^2 = 0.795$, indicating a very large effect size. Students taught with TIBLEP outperformed those taught with traditional methods.

RQ3: Moderating Effect of Socioeconomic Background on Attitudes

Socioeconomic background significantly moderated attitudinal outcomes: students from higher-SEB backgrounds reported more positive attitudes toward Natural Science after exposure to TIBLEP than their lower-SEB peers. SEB did not, however, significantly affect achievement outcomes (see Table 3).

RQ4: Effect of Socioeconomic Background on Achievement

ANCOVA results (Table 3) indicated that SEB did not exert a statistically significant main effect on achievement, $F(1, 195) = 1.13$, $p = 0.253$, partial $\eta^2 = 0.100$. Although SEB shaped attitudes, it did not significantly moderate achievement outcomes, suggesting that TIBLEP benefits students across socioeconomic groups comparably in terms of performance.

RQ5: Gender Differences in Attitudes and Achievement

ANCOVA results (Table 3) showed no significant main effect of gender on achievement, $F(1, 195) = 0.025$, $p = 0.874$, partial $\eta^2 = 0.000$, and the Treatment × Gender interaction was similarly non-significant,

F(1, 195) = 1.05, p = 0.306. Gender did not significantly influence either attitudinal disposition or achievement, with male and female students benefiting comparably from TIBLEP.

7. Discussion

The findings provide compelling evidence that TIBLEP significantly improved students' attitudes toward Natural Science and their academic achievement compared with traditional lecture-based instruction. The very large effect sizes confirm that the instructional strategy was a decisive factor in shaping outcomes: students exposed to TIBLEP developed more positive dispositions toward science and achieved higher scores, whereas those taught conventionally showed only modest gains. This pattern suggests that structured, technology-supported inquiry can shift classroom learning in ways that traditional approaches struggle to match — a finding directly relevant to efforts to build sustainable science education systems in resource-constrained contexts.

The improvement in attitudes aligns with global evidence that inquiry-based learning fosters curiosity, motivation, and engagement. Freeman et al. (2014) demonstrated, across hundreds of STEM studies, that active-learning strategies consistently outperform lectures, reducing failure rates and improving conceptual understanding. Ganajová et al. (2025) similarly confirmed that inquiry-based interventions enhance motivation and affective outcomes across diverse contexts. The present study extends this evidence to Nigerian junior secondary classrooms, showing that even in resource-constrained environments, offline inquiry packages can meaningfully shift students' perceptions of science.

Achievement outcomes mirrored these attitudinal gains, with effect sizes exceeding those typically reported for inquiry-based interventions — likely because TIBLEP provided structured scaffolding that balanced learner autonomy with guided support. This finding aligns with Kirschner, Sweller, and Clark's (2006) argument that minimally guided inquiry can overwhelm novice learners, whereas structured inquiry provides the balance needed for durable learning gains. TIBLEP's integration of inquiry tasks, immediate feedback, and curriculum alignment reflects this principle and plausibly explains why students performed so strongly.

Socioeconomic background played a more complex role. Students from higher socioeconomic backgrounds reported more positive attitudes toward science, consistent with Kyriakides et al.'s (2018) review finding that resource advantages shape learners' dispositions, and with Vadivel et al. (2023), who found that the benefits of inquiry-based learning are moderated by contextual inequality. Encouragingly, SEB did not significantly affect achievement outcomes, suggesting that TIBLEP benefits students across socioeconomic groups comparably in terms of performance, even where attitudinal differences persist. This pattern echoes UNESCO's (2023) caution that pedagogy alone cannot close structural gaps, underscoring the need for complementary policies that address resource disparities directly.

Gender differences were negligible, with male and female students benefiting comparably from TIBLEP. This is consistent with Ganajová et al. (2025), who found that inquiry-based interventions improved motivation across genders, and with Teplá and Distler (2025), who found that structured inquiry

narrowed gender gaps in conceptual understanding. The present study adds to this literature by showing that offline, technology-supported inquiry can be implemented in Nigerian classrooms without exacerbating gender disparities — a null finding that is itself informative, since it suggests TIBLEP promotes equity in science learning rather than simply raising average performance.

Taken together, these findings contribute to theory and practice in several ways. They reinforce constructivist principles by showing that learners build knowledge more effectively through active engagement than passive reception. They support guided-inquiry frameworks by demonstrating that structured scaffolding is essential for novice learners. And they highlight the importance of evaluating instructional innovation not only for effectiveness but also for equity — situating technology-enhanced inquiry within the broader, sustainability-oriented debate about access to quality education.

Theoretical, Equity, and Policy Implications

At the theoretical level, these findings reinforce the constructivist view that learners build knowledge more effectively through active engagement with problems than through passive reception. TIBLEP's success demonstrates that inquiry-based approaches, when carefully structured, can foster deeper understanding and stronger attitudes toward science, supporting Kirschner, Sweller, and Clark's (2006) argument that minimally guided inquiry can overwhelm novices, whereas guided inquiry with appropriate scaffolding balances learner agency with instructional support. By embedding inquiry tasks, providing immediate feedback, and aligning with the curriculum, TIBLEP illustrates how structured inquiry can be implemented sustainably in resource-constrained contexts.

The equity implications are equally significant. This study demonstrates that instructional innovation must be evaluated not only for effectiveness but also for fairness. Testing socioeconomic background and gender situates technology-enhanced inquiry within broader debates about equitable access to quality science education; the finding that gender did not significantly influence outcomes suggests TIBLEP can be implemented without exacerbating disparities, while the moderating effect of socioeconomic background on attitudes underscores the continuing need to address structural inequalities in resources and opportunity.

From a policy perspective, curriculum planners should integrate offline, inquiry-driven digital packages such as TIBLEP into science instruction in a structured, coherent, and learning-objective-aligned manner. Teachers need sustained professional development, as short-term workshops are insufficient to build the confidence and expertise required to facilitate inquiry lessons effectively. Policymakers should prioritize equitable resourcing for schools serving low-socioeconomic communities, since pedagogy alone cannot close achievement gaps rooted in structural disadvantage without targeted investment. Finally, assessment reform is needed: embedding formative assessment within instructional sequences, as modeled in TIBLEP, can transform errors into learning opportunities and foster resilience and deeper engagement among students.

Taken together, these implications position TIBLEP as both an effective instructional innovation and a model for adapting technology-enhanced inquiry to advance sustainable, equitable science education — contributing to theoretical debates on constructivism and guided inquiry while offering practical guidance for curriculum design, teacher development, resource allocation, and assessment reform.

8. Limitations and Future Research

While the findings are robust, several limitations remain. The sample was relatively small and non-randomised, limiting generalisability, and the ten-week intervention leaves open questions about long-term sustainability. Teacher fidelity was monitored but not quantified, and qualitative data on classroom processes were limited. Future research should pursue longitudinal and mixed-methods designs, larger multi-school samples, and process-level analyses — such as video-coded classroom interactions — to explore the mechanisms underlying TIBLEP's effectiveness.

9. Conclusions

This study provides strong evidence that TIBLEP is an effective instructional innovation for junior secondary Natural Science in Nigeria. By embedding inquiry-driven tasks, immediate feedback, and curriculum alignment within an offline digital platform, TIBLEP significantly improved students' attitudes toward science and their academic achievement compared with traditional lecture-based instruction. Very large effect sizes confirm that the instructional strategy was a decisive factor in shaping outcomes.

Importantly, TIBLEP's benefits were consistent across genders, suggesting the approach can be implemented equitably without exacerbating disparities. Socioeconomic background moderated attitudinal outcomes, with higher-SEB students reporting more positive dispositions, but it did not significantly affect achievement — indicating that while instructional innovation can lift performance across groups, structural inequalities in resources and opportunity continue to shape students' perceptions of science.

Taken together, these findings contribute to the international literature by confirming the value of structured, technology-supported inquiry; to African scholarship by extending this evidence to the Natural Sciences; and to sustainability and equity debates by showing that TIBLEP benefits all groups comparably in terms of achievement. The study reinforces constructivist principles, validates guided-inquiry frameworks, and situates technology-enhanced learning within the broader effort to build equitable, sustainable access to quality science education.

Recommendations

Curriculum integration

Curriculum planners should integrate offline, inquiry-driven digital packages, such as TIBLEP, into science instruction to ensure that inquiry is structured, coherent, and aligned with learning objectives.

Teacher professional development

Teachers must be supported through sustained professional development, as short-term workshops alone are insufficient to build the confidence and expertise needed to facilitate inquiry-based lessons effectively.

Equitable resourcing

Policymakers should prioritize equitable resourcing, particularly for schools serving low-socioeconomic communities. Providing functional computers, offline digital tools, and supportive infrastructure is essential, since pedagogy alone cannot close achievement gaps rooted in structural disadvantage.

Assessment reform

Embedding formative assessment within instructional sequences, as modeled in TIBLEP, can transform errors into learning opportunities rather than markers of failure, fostering resilience and deeper engagement among students.

Future research directions

Future research should adopt longitudinal and mixed-methods designs to test the durability of attitudinal and achievement gains, explore the mechanisms underlying technology-enhanced inquiry learning, and examine how teacher enactment and classroom processes shape outcomes. By combining instructional innovation with equitable policy measures, Nigeria can move closer to a science education system that is both sustainable and inclusive, fostering problem-solving, critical thinking, and conceptual understanding among its future scientists.

Abbreviations

TIBLEP
Technology–Enhanced Inquiry–Based Learning Package
SEB
Socio–Economic Background
STEM
Science, Technology, Engineering and Mathematics
ANCOVA
Analysis of Covariance
NSATS
Natural Science Attitudinal Scale
NSAS
Natural Science Achievement Scale

Declarations

Author Contribution

H.B.B. made substantial contribution to the conception and design of the work, and the acquisition, analysis, interpretation and creation of the learning package used in this work. U.R. revised this work critically for important intellectual content, approved the version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy of any part of the work are appropriately investigated and resolved.

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Figures

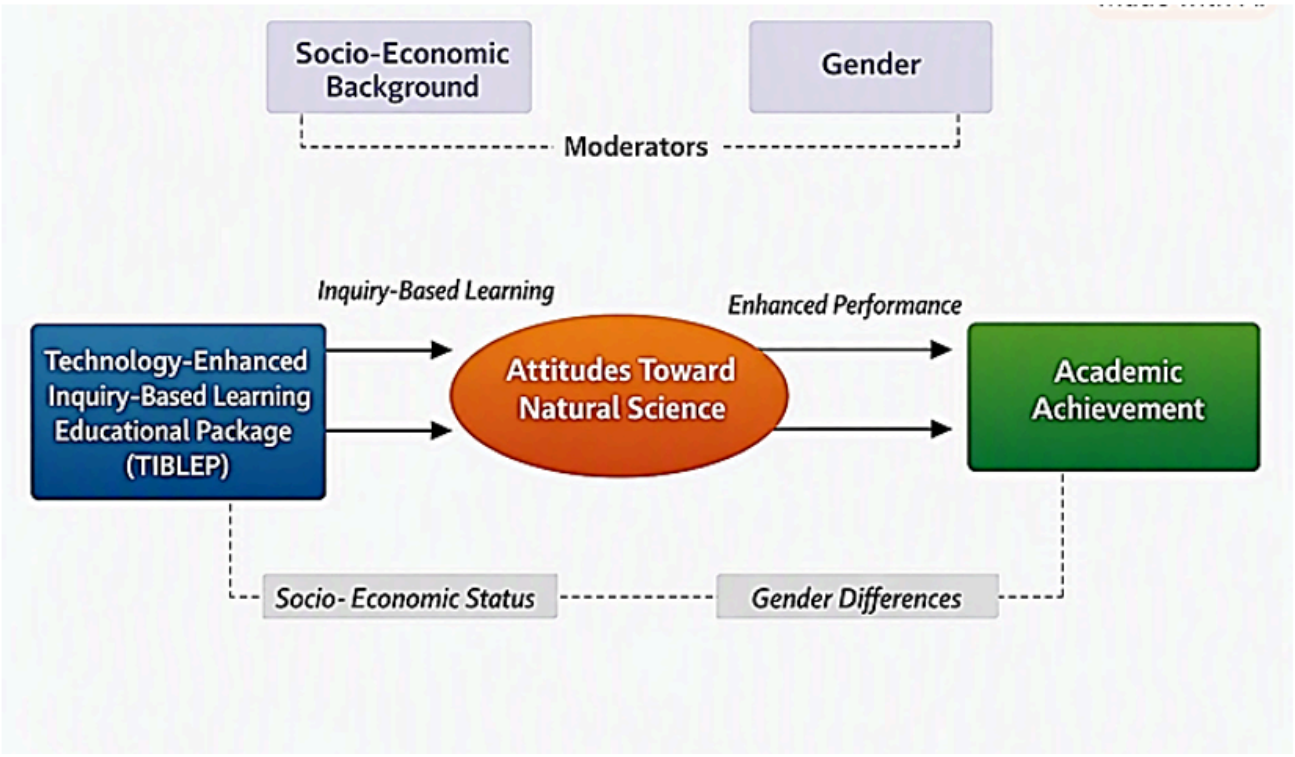


Figure 1

Conceptual Framework of TIBLEP