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Public-private achievement gaps in Lagos chemistry education: An ecological analysis of teacher and institutional factors

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Abstract

Despite chemistry's foundational role in scientific literacy, Nigerian secondary school students consistently demonstrate poor learning outcomes. This study examines the relationships among learning environment, teacher characteristics, and chemistry achievement among 1,500 senior secondary school II students from 50 schools in Lagos State Education District IV, using two system levels of Bronfenbrenner's ecological systems theory as an interpretive framework. Students completed a 50-item chemistry achievement test and questionnaires. Results reveal significant achievement differences between private (mean [M] = 27.94) and public school students (M = 17.13), t (1,498) = -28.82, p < .001, d = 2.14. Teacher characteristics correlate with students' achievement r (1,498) = .346, p < .001, while learning environment perceptions and attitudes show no significant relationships. These findings suggest that school type (exo-system) and teacher quality (microsystem) are meaningfully associated with chemistry learning outcomes in this context, though the cross-sectional design prevents causal interpretation.

Keywords: chemistry education, learning environment, teacher characteristics, Bronfenbrenner's ecological systems theory, institutional factor

INTRODUCTION

Nigerian secondary school students have consistently performed poorly in chemistry over the past two decades. West African Examinations Council (2023) data from 2019 through 2023 show mean (M) scores ranging from 31 to 54 in paper 2 (theory) and 25 to 28 in paper 3 (practical), indicating that most students do not achieve mastery of foundational chemistry concepts. Poor performance has persisted despite educational reforms since the early 2000s (Edomwonyi-Otu & Avaa, 2011; Oloruntegbe, 2000). Concerns over performance extend beyond individual academic outcomes: chemistry serves as a gateway to careers in medicine, engineering, and pharmacy (Ababio, 2010), and poor performance constrains the pipeline of qualified professionals entering STEM fields (Okebukola, 2019).

Between 1999 and 2009, fewer than 30 percent of students achieved credit passes in WAEC chemistry (Oludipe & Awokoy, 2010), and scores across 2019-2023 remain well below mastery levels. This trend in poor chemistry performance is well illustrated in **Table 1**. Research identifies atomic structure, chemical bonding, stoichiometry, and electrochemistry as particularly challenging topics (Kyado et al., 2021), with high-performing students struggling more with conceptual understanding than factual recall (Iroegbu, 2020). These patterns point to systemic instructional challenges rather than isolated content difficulties.

Previous studies have identified various contributing factors: teacher attitudes (Agbadiuno, 1992), instructional methods (Omwirhiren & Ibrahim, 2016), laboratory resources (Bajah, 1999), and school location effects (Ogunleye, 2002). These investigations, however, typically examine single factors rather than exploring

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Contribution to the literature

- This study is the first ecological analysis of chemistry achievement in Nigerian secondary schools, addressing the limited empirical research base in sub-Saharan African chemistry education.
- It is the novel application of Bronfenbrenner's (1979) EST to chemistry education in developing country contexts, demonstrating how factors at multiple system levels interact to influence learning outcomes.
- Its findings identify teacher characteristics as explaining 12% of achievement variance while institutional structures (school type) account for 36%, providing actionable insights for chemistry educators and policymakers globally. While situated in Nigerian context, findings have relevance for chemistry education in resource-constrained settings worldwide where similar institutional disparities exist.

Table 1. National chemistry achievement in WAEC examinations (2019-2023): Context for study

Year	M (SD)		Total students
	Paper 2	Paper 3	
2019	31.0 (14.46)	27.0 (9.22)	762,175
2020	54.0 (17.83)	27.0 (6.93)	750,175
2021	49.0 (15.94)	27.0 (8.77)	-
2022	45.0 (12.04)	28.0 (9.34)	801,522
2023	34.0 (14.35)	25.0 (8.00)	842,030

Note. Source: WAEC Chief Examiner Reports (2019-2023)

how multiple influences operate within students' broader learning contexts. This represents a significant gap in the Nigerian chemistry education literature. While individual studies document that teacher quality matters (Cleopas & Onwuchekwa, 2024) and that school type is associated with achievement (Härmä, 2013), the field lacks frameworks that explain how these factors operate across different systemic levels, from immediate classroom interactions to institutional structures to broader policy contexts. This study addresses the existing theoretical gap using the exo-system and microsystem levels of Bronfenbrenner's (1979) ecological systems theory (EST) to explain how the learning environment and teachers' characteristics operate, while providing a large-scale examination. Applying this framework to Lagos chemistry education allows examination of how multiple factor levels relate to achievement, moving from documenting what is associated with outcomes to understanding how those associations possibly operate.

Purpose of Study

This research investigates the associations between students' perceptions of their learning environment, teacher characteristics, and chemistry learning outcomes among senior secondary school II students in Lagos State, Nigeria. Given the cross-sectional design with non-random assignment to school types, the study examines correlational patterns rather than causal relationships. The following research questions (RQs) guided this investigation:

RQ1: How are school type and students' individual perceptions of learning environment associated with chemistry achievement?

RQ2: How do students' perceptions of teacher characteristics relate to learning outcomes in chemistry?

RQ3: How do students' attitudes toward chemistry correlate with their achievement?

Theoretical Framework

Bronfenbrenner's (1979) EST provides an interpretive scaffold in this study, rather than a comprehensive empirical test of the full ecological model. EST, as a framework, conceptualizes human development as occurring within nested environmental contexts, each exerting distinct influences on outcomes (Bronfenbrenner & Morris, 2006). The nested environment comprises four systems: the mesosystem, macrosystem, microsystem, and exo-system. Recent scholarship confirmed the continuous relevance of EST in educational research, noting that many studies adopt the EST framework rather than the more complex bioecological model (Tong & An, 2024).

In this study, the microsystem focuses on interactions within learning environments and students' perceptions of their teachers (El Zaatari & Maalouf, 2022). The mesosystem connects these immediate settings, particularly through home-school linkages; home learning environments, parental involvement, and family educational expectations consistently predict achievement (Lee & Burkam, 2003; Lubienski & Lubienski, 2014). Although these variables were not measured in this study, their influence on observed patterns is acknowledged throughout. At the exo-system level, institutional structures affect students indirectly: school type (public versus private) serves as our primary exo-system variable, proxying for resource allocations, teacher compensation and retention, class sizes, facility quality, and accountability structures (Tooley et al., 2010), all of which shape microsystem quality without students participating in those decisions. Finally, the macrosystem encompasses the socio-cultural context, such as WAEC-aligned national curriculum, Nigeria's dual public-private school structure, and societal expectations regarding science education. This explicit mapping explains variable-to-level correspondences.

However, this study explores the micro- and exo-systems level of the EST framework. The direct absence of meso- and macro- level reflects a deliberate scope decision rather than a theoretical oversight. Measuring the mesosystem would require household surveys; this study's institutional authorization and resources could not be accessed. Similarly, the macrosystem level demands policy-level data that are unavailable at the district and school level of analysis employed within this study.

Literature Review

Synthesizing across existing studies reveals a different pattern across widely varied studies, from teacher attitudes to laboratory resources to instructional methods. This variation suggests either that multiple independent factors each contribute modestly to achievement or that unmeasured third variables, such as school resources or student socio-economic status (SES), confound relationships reported in single-factor analyses. The absence of multi-factor studies examining simultaneous effects leaves these alternative explanations unresolved. International science education research increasingly recognizes that learning environments, teacher quality, and institutional contexts interact in complex ways (Holbrook & Rannikmae, 2009; National Research Council, 2012), yet Nigerian chemistry research has not adopted these theoretically grounded approaches. This study begins addressing that gap.

Teacher characteristics and chemistry achievement

Following Shulman's (1987) foundational framework, effective teaching requires both subject matter content knowledge and pedagogical content knowledge, that is, understanding how to represent specific content to make it comprehensible to learners. Ball et al. (2008) identified 'knowledge of content and students' (awareness of common misconceptions) and 'knowledge of content and teaching' (facility with effective instructional representations) as critical dimensions of mathematics and science teaching competence. Subsequently, Marifa et al. (2023) found that chemistry teachers' pedagogical content knowledge in teaching hybridization varied considerably across practitioners, with direct implications for student conceptual understanding, reinforcing the importance of treating pedagogical content knowledge as domain-specific and context-sensitive rather than as a unitary attribute that transfers across content areas.

Research consistently identifies teacher quality as among the most influential school-based predictors of student achievement (Hattie, 2009). In the Nigerian context, Cleopas and Onwuchekwa (2024) found that teacher qualification and years of experience significantly predicted chemistry performance, while Omwirhiren and Ibrahim (2016) documented that instructional method substantially influenced learning outcomes. These findings align with López-Martín et al. (2023) meta-analytic evidence that teacher characteristics explain approximately 9 percent of variance in secondary students' performance across multiple contexts.

Recent evidence reinforces the centrality of teacher quality while noting context dependencies. Kang and Keinonen (2018) found that teacher content knowledge predicted student science achievement in high-performing systems, showing weaker effects in under-resourced contexts, where structural constraints such as class size and material scarcity may limit what even well-prepared teachers can accomplish. This pattern suggests that teacher characteristics matter most when environmental conditions enable effective instruction, an interaction that single-level analyses cannot detect.

Beyond generic quality measures, teacher effectiveness in chemistry is also constrained by subject-specific instructional demands that compound structural limitations. Asaki and Adu-Gyamfi (2025) found that factors intrinsic to the content itself, particularly the abstract conceptual demands of organic chemistry, are among the strongest predictors of teaching difficulty at the secondary level. This finding provides an important bridge between Nigerian and international literatures: the challenge of chemistry instruction is beyond resource scarcity or teacher qualifications in the abstract but also the epistemological nature of chemistry. which requires sustained engagement with representations, models, and abstractions that are cognitively demanding regardless of setting. Research designs that treat teacher quality as a single construct, without disaggregating it by content domain or by the demands that specific content places on both teachers and students, are likely to underestimate its complexity

Learning environment and achievement

Theoretical foundations have addressed the concept of "learning environment" differently; therefore, learning environment is not a monolithic construct. Bronfenbrenner's (1979) EST describe learning environments (the classroom and school) as being embedded within and shaped by broader institutional, community, and societal systems. Bronfenbrenner (1979) situates classroom-level constructs such as class size or resource availability within structural conditions that themselves require explanation, rather than treating them as independent causal agents. Applied to Nigerian secondary schooling, this means that school-level resources must be understood as partly constituted by funding inequities between school type and geographic disparities in infrastructure investment. This is not simply a variable feature of individual schools. On the other hand, Vygotsky's (1978) situated learning as fundamentally mediated by social interaction, tool use, and the zone of proximal development implies that classroom environments are consequential not primarily as physical settings but as structures for interaction and scaffolding. From this perspective, what matters most in the learning environment is the quality of teacher-student interaction and the opportunities it creates for cognitive support at the boundary of students' current and emerging capabilities. This is consistent with Fraser's (2012) evidence, derived from the what is happening in this class? Instrument. This study showed that psychosocial dimensions of the classroom environment, particularly teacher support and student cohesion, predict science achievement more strongly than physical infrastructure. Vygotsky's (1978) framework provides a theoretical explanation for this empirical finding: psychosocial dimensions matter because they are the vehicle through which learning-enabling interaction occurs.

Moos (1979) study on person-environment fit went further by distinguishing between the objective features of an environment and the subjective experience of that environment by its participants. Moos (1979) argued that the same physical setting can facilitate or constrain environment depending on how students and teachers perceive and interpret it. This perceptual dimension is precisely what student perception measures, in this study. Observable teacher behaviors such as clarity of explanation, enthusiasm, and approachability are important, because students' perception of these behaviors shapes their engagement, motivation, and performance.

These theoretical traditions review physical features of the environment, including infrastructure, laboratory equipment, and class size, and operate primarily through the first and second traditions. The physical features enable or limit interaction and set a baseline beneath which effective teaching is structurally impeded, regardless of teacher characteristics. Psychosocial features operate primarily through the second and third traditions: they shape the quality of interaction and the student experience of that interaction. These two dimensions do not function identically across contexts. In severely under-resourced settings, where most schools share inadequate physical infrastructure, variance in physical environment is effectively truncated, making it a weak predictor of differential achievement. This leaves psychosocial variation as the more consequential differentiating dimension, though existing Nigerian studies rarely make this theoretical distinction explicit.

Fraser (2012) distinguished physical learning environments (facilities, materials, class size) from psycho-social environments (teacher-student relationships, peer interactions, classroom climate). In the Nigerian context, Udoh (2012) found associations between learning environment and chemistry achievement in Akwa Ibom State; the relationship was mediated by resource utilization patterns and pedagogical approaches, suggesting that environmental quality influences achievement through the practices it enables rather than directly. This finding aligns with the Vygotskian premise that environments matter through the practices they enable, not through their physical properties alone. The difference between Nigerian and international findings may therefore reflect not a genuine divergence in the operation of learning environment effects, but rather that Nigerian studies have more often measured physical than psychosocial conditions, resulting in weaker and more inconsistent estimates of what is in fact a robust underlying relationship.

School type and selection effects

Private schools in Lagos often achieve better outcomes than public schools (Tooley et al., 2010). International research, however, demonstrates that school type is neither a simple nor transparent explanatory variable. Lubienski and Lubienski's (2014) comprehensive US analysis found that apparent private school advantages disappeared after controlling student demographics, with public schools outperforming private schools among demographically comparable students. Chudgar and Quin (2012) reported similar patterns in India: raw achievement gaps favored private schools but diminished substantially after socio-economic adjustments.

These findings imply selection bias: families choosing private schools differ systematically from those using public schools in SES, parental education, educational values, and home resources, all factors that independently predict achievement (Lee & Burkam, 2003). Observed school-type differences align with institutional quality and student composition. Härmä's (2013) ethnographic work in Lagos documented this directly: families selecting low-cost private schools had higher educational aspirations and greater sacrifices for their children's education, even when such schools offered only marginal improvements in quality over public alternatives. Our cross-sectional design cannot address this confound. Documenting the magnitude of achievement gaps, while acknowledging their ambiguous origins, nonetheless provides valuable descriptive evidence for policy discussions about educational equity.

School-type comparisons provide descriptive evidence about the magnitude of achievement disparities between sectors under current institutional arrangements without the strong causal interpretations that observational data cannot support. Such descriptive evidence is not inconsequential: documenting that gaps exist, even without fully accounting for their origins, is relevant to policy discussions about educational equity and about what kinds of institutional arrangements are associated with better outcomes for which students under what structural conditions.

Attitudes and achievement

Research on attitudes toward science and academic achievement generally finds positive but moderate relationships (Osborne et al., 2003). A recent study examined factors affecting chemistry attitudes across multiple countries (Musengimana et al., 2021), identified teacher characteristics, instructional methods, and learning environment quality as consistently associated with both attitudes and achievement. The review noted that most available studies employ cross-sectional designs, limiting causal inference. In high-stakes testing contexts such as Nigeria's, achievement may depend more on study discipline and test preparation than on intrinsic interest, potentially weakening observable attitude-achievement relationships.

METHOD

This study employed a quantitative descriptive survey research design examining associations between student perceptions of teacher characteristics and learning environments (independent variables) and chemistry achievement (dependent variable), with school type (public and private) as a grouping variable.

Population, Sample, and Sampling Technique

All senior secondary school II chemistry students in Education District IV constituted the target population. The accessible population consisted of students from 43 public schools and 7 private schools. The 43:7 ratio of public to private schools reflects the actual distribution in District IV, where public schools vastly outnumber private institutions. Lagos State operates a predominantly public education system, with private schools serving approximately 15 to 20 percent of secondary students (Härmä, 2013). Our sample distribution includes: 1,290 public school students (86%) and 210 private school students (14%), closely matching the district's public-private enrollment proportions.

Private schools were selected through stratified random sampling to ensure representation across fee levels. The 12 registered private schools in District IV, as at the time of this study, were categorized into three fee bands: low-cost (at or below N50,000 per term, n = 5), mid-range (N50,001-N150,000 per term, n = 4), and high-cost (above N150,000 per term, n = 3). Schools were randomly selected from each band proportionate to their representation, yielding seven schools (three low-cost, three mid-range, and one high-cost). This stratification ensured the private school sample included institutions across all social classes. All 43 public schools in District IV participated, eliminating selection bias at the public school level. These schools were across urban and peri-urban zones: 28 schools (65%) in urban Lagos (areas with full municipal services, paved roads, and reliable electricity) and 15 schools (35%) in peri-urban areas (partially developed neighborhoods with mixed infrastructure). Geographic distribution was not analyzed as a separate variable or used in interpreting between-school variation (resources and outcomes). From each school, 30 chemistry students were selected through simple random sampling using class rosters, yielding a planned sample of 1,500 students. All selected students participated, producing a final sample of 1,500 (100 percent response rate).

Research Instruments

Chemistry achievement test

A 50-item multiple-choice test was developed based on the senior secondary school chemistry curriculum and WAEC standards. Questions covered 18 topics from senior secondary I and senior secondary II syllabi, with four options per item. Content was distributed across key topical areas: atomic structure and periodic classification (10 items, 20%), chemical bonding and reactions (12 items, 24%), stoichiometry and quantitative chemistry (10 items, 20%), organic chemistry fundamentals (10 items, 20%), and states of matter and electrochemistry (8 items, 16%). Using Bloom's taxonomy, the cognitive demand was knowledge and recall (24 items, 48%), comprehension and application (18 items, 36%), and analysis and synthesis (8 items, 16%). The chemistry achievement test items were drawn from past WAEC question papers and reviewed by experienced chemistry teachers for curriculum alignment, language clarity, and distractor quality. Each correctly answered item scored 1 point with no penalty for incorrect responses, yielding a maximum score of 50.

Student questionnaire

A 20-item instrument was developed using a 4-point Likert scale (strongly agree to strongly disagree). Four sections assessed: student attitudes toward chemistry (5 items), parent interest (5 items), learning environment perceptions (5 items covering physical facilities, classroom conditions, and general learning atmosphere), and teacher characteristics (5 items covering students' perceptions of teacher enthusiasm, clarity of explanation, approachability, perceived subject mastery, and fairness in assessment). The teacher characteristics subscale measured perceived teacher behaviors rather than objective qualifications, formal pedagogical training, or observed instructional practices. Data from the parent interest subscale were collected but are not analyzed in this study, as they address a separate RQ that will be reported in a subsequent study. The three subscales analyzed here are student attitudes, learning environment perceptions, and teacher characteristics.

Instrument Validation

Content validation was carried out by a 2-member expert panel: a university chemistry education lecturer with 15 years of experience in curriculum and assessment, and a secondary chemistry teacher with 18 years of classroom experience and formal training in test development. This composition represents subject-matter depth and classroom-level judgment appropriate for senior secondary II level. Each validator independently reviewed all 50 items against a content specification table, rating each item on two criteria using 3-point scales: presence in curriculum representativeness for senior secondary II level (1 = not present, 2 = somewhat present, 3 = fully present) and cognitive appropriateness for the target population. Items with M ratings below 2.5 or disputed cognitive level classifications were replaced with alternative WAEC items before pilot testing. The proportion of items rated 2 or 3 by both validators was .87, indicating strong agreement that the assembled instrument adequately covered the intended syllabus domain.

Item quality and instrument reliability were assessed through a pilot study conducted with 50 senior secondary II chemistry students drawn from education district II, one public and one private. While the item difficulty indices for the achievement test ranged from .32 to .78 (M = .58), and discrimination indices, calculated through point-biserial correlations between item scores and total test scores, ranged from .25 to .67 (M = .44). The split-half reliability coefficient for the achievement test was r = .785. The Cronbach's alpha for the student questionnaire was α = .873, indicating acceptable internal consistency for both instruments.

Data Collection

Permission was obtained from the appropriate school authorities in Lagos State Education District IV, and parent-informed consent forms were signed. Instruments were administered to students during regular school hours with assistance from chemistry teachers at each school. Students were assured of confidentiality and encouraged to respond honestly. All 1,500 questionnaires and achievement tests were completed and returned, yielding a 100% response rate.

Data Analysis

Data analysis proceeded in three phases. First, descriptive statistics characterized the sample and key variables, including measures of central tendency, dispersion, and distributional properties. Second, bivariate analyses assessed associations using Pearson correlation coefficients for continuous variables and independent-samples t-tests for group comparisons. Third, hypothesis testing employed inferential statistics with alpha set at .05. Effect sizes were calculated for all significant findings using Cohen's (1988) d for t-tests and Pearson's r for correlations, interpreted following Cohen's (1988) conventions: small (d = 0.20, r = .10), medium (d = 0.50, r = .30), and large (d = 0.80, r = .50).

Table 2. Descriptive statistics for chemistry achievement, learning environment, and teacher characteristics by school type

Variable	M (SD)		
	Public schools (n = 1,290)	Private schools (n = 210)	Total sample (N = 1,500)
CSAT	17.13 (5.05)	27.94 (5.05)	18.65 (6.23)
SPLE	59.22 (5.35)	58.76 (5.35)	59.12 (5.54)
TC	14.95 (2.85)	16.20 (2.75)	15.11 (2.84)

Note. CSAT: Chemistry student achievement test; SPLE: Students' perception of learning environment; TC: Teacher characteristics

The analysis treated all 1,500 students as independent observations, though students were nested within 50 schools; the implications of this analytical decision are addressed in the limitations section. It is important to note that treating clustered observations as independent violates the assumption of independence and may produce underestimated standard errors, inflated type I error rates, and misleading significance levels.

RESULTS

Descriptive Statistics

Descriptive statistics for all study variables are presented in Table 2. Chemistry achievement scores ranged from 0 to 50 (M = 18.65, standard deviation [SD] = 6.23), indicating generally poor performance, with students averaging 37.3 percent on the assessment. Students' perceptions of their learning environment showed relatively high ratings (M = 59.12, SD = 5.54 on a scale of 20 to 80), while teacher characteristics averaged 15.11 (SD = 2.84) on a scale of 5 to 20. Examination of histograms and normal quantile-quantile plots indicated approximately normal distributions for all continuous variables.

Correlation Analyses

Pearson correlation coefficients among continuous study variables are displayed in Table 3. Students' perceptions of teacher characteristics demonstrated a significant moderate positive correlation with chemistry achievement, r (1,498) = .346, p < .001, 95% confidence interval [CI] [.296, .394]. Students' perception of learning environment showed no significant correlation with achievement, r (1,498) = -.023, p = .368, 95% CI [-.074, .028]. There is no significant correlation between students' attitudes toward chemistry and achievement, r (1,498) = -.023, p = .368.

Research Questions

RQ1: How are school type and students' individual perceptions of learning environment associated with chemistry achievement?

Private and public school students showed a significant difference in achievement (t = -28.82, df =

Table 3. Pearson correlations among continuous study variables

Variables	1	2	3	M (SD)	Significance (2-tailed)
1. Students' perception of learning environment	1			59.12 (5.54)	-
2. Chemistry student achievement test	-.023	1		18.65 (6.23)	.368
3. Teacher characteristics	.346**	.346**	1	15.11 (2.84)	< .001
4. Student attitudes	-.023	-.023	.298**	-	.368

Note. **Correlation is significant at the .01 level (2-tailed) & N = 1,500

1498, $p < .001$, $d = 2.14$). **Table 2** presents private school students ($M = 27.94$, $SD = 5.05$) substantially outperforming public school counterparts ($M = 17.13$, $SD = 5.05$). The $d = 2.14$ effect size is exceptional by international standards: Cohen's (1988) conventions classify $d > 0.80$ as 'large,' and published school-type comparisons rarely approach this magnitude.

The practical significance of this gap is considerable. Private school students averaged 56 % on the test versus 34 % for public school students, a 22 % difference revealing a distinction between approaching basic competency and failing to demonstrate minimal proficiency. This exceeds typical international school-type findings: Lubienski and Lubienski (2014) reported raw U.S. public-private mathematics achievement gaps around $d = 0.30$, and Chudgar and Quin (2012) found $d = 0.45$ in India. The Lagos gap is four to seven times larger.

Several factors could be responsible for this large effect size.

a. Unequal sample sizes (1,290 public versus 210 private students) create group asymmetry, though this primarily affects sampling error rather than effect size magnitude.
b. Institutional disparities in Lagos are extreme relative to contexts: many public schools in our sample lacked functional laboratories and operated with class sizes exceeding 60 students. Even low-cost private schools typically maintained better facilities, smaller classes, and more stable staffing.
c. Student composition differences remain unmeasured. Families selecting private schools differ systematically in SES, parental education, and home resources, all of which independently predict achievement. The observed gap confounds selection effects with any institutional quality differences.

$d = 2.14$ is interpreted as a descriptive index quantifying achievement inequality in Lagos chemistry education rather than as evidence that private schooling causes large achievement gains. Beyond the large effect size, the magnitude of d warrants scrutiny for potential measurement artifacts. As shown in **Table 2**, the equal SDs across groups ($SD = 5.05$ in both public and private samples) suggest acceptable homogeneity of variance. Although the cause was not established, the varied group composition (1,290 public versus 210 private students) and ceiling effect within each group could be responsible for this magnitude. Therefore, $d=2.14$ cannot be purely treated as an index of institutional effects.

Students' individual perceptions of learning environment showed no significant correlation with achievement ($r = -.023$, $p = .368$). This null finding reflects a level-of-analysis issue: the student-level analysis examined whether individuals perceiving better environments achieved more than same-school peers, not whether schools with better environments showed better overall outcomes. This distinction is elaborated in the limitations section

RQ2: How do students' perceptions of teacher characteristics relate to learning outcomes in chemistry?

Table 3 shows students' perceptions of teacher characteristics have a significant moderate positive correlation with achievement ($r = .346$, $p < .001$). These teachers' perceptions explain approximately 12 percent of variance in student achievement ($r^2 = .120$), a finding consistent with López-Martín et al. (2023) meta-analytic estimate of approximately 9 percent explained variance.

RQ3: How do students' attitudes toward chemistry correlate with their achievement?

Table 3 shows that students' self-reported attitudes toward chemistry did not significantly predict performance on the standardized chemistry assessment in this sample ($r = -.023$, $p = .368$).

DISCUSSION

Associations among school type, student perceptions of learning environments, teacher characteristics, and chemistry achievement were examined through the interpretive lens of Bronfenbrenner's (1979) EST (Tong & An, 2024). Results reveal patterns consistent with multi-level ecological influences on achievement, although the cross-sectional design prevents causal claims.

Situating Findings Within Theory

These contributions connect to broader theoretical conversations in science education that extend well beyond the Nigerian context. The public-private achievement gap observed here aligns with growing evidence that such gaps reflect structural disadvantage rather than individual deficits (Calabrese Barton & Tan, 2020). When systemic factors dominate to the degree suggested by the finding, interventions targeting student motivation or attitudes address the wrong level of the problem. As the non-significant attitudinal correlations are reinforced.

The pattern of results speaks to a persistent tension between universal theoretical claims and context-specific evidence. The weak learning environment correlation challenges the generalizability of cross-national environmental effects (Fraser, 2012), demonstrating that in severely under-resourced contexts, students' perceptions may contest meaningful education environments. This finding is consistent with Praetorius et al. (2024) that theoretical assumptions built on adequately resourced schools require explicit re-examination when those conditions do not hold. The Nigerian context contributes to this literature by documenting precisely what happens when foundational assumptions, functional laboratories, qualified and consistently present teachers, and adequate materials cannot be undermined.

Beyond these substantive findings, the study's acknowledged limitations point toward a structural problem in African science education scholarship more broadly: the conditions required for definitive causal research, longitudinal tracking, socio-economic controls, multilevel modelling, and institutional data infrastructure are precisely those that resource-constrained research environments struggle to provide. Limited funding, absent student tracking systems, privacy constraints on school access, and emerging institutional capacity are not incidental obstacles but systemic features of the research landscape that shape what can and cannot be answered at any given time. Policy, however, cannot wait for ideal conditions to materialize. This study's contribution lies partly in demonstrating what can be established within current constraints and in making visible the methodological investments sustained funding, shared data infrastructure, and collaborative research networks that would enable more definitive answers to unresolved questions in Nigerian chemistry education.

School Type Associations: Patterns Consistent with Exo-System Influences

With the selection bias constraint in mind, we explore possible mechanisms through which institutional differences might relate to achievement patterns. The achievement gap (d = 2.14) is consistent with EST's exo-system influences: institutional structures and resource allocation patterns that shape developmental contexts. At the exo-system level, private schools typically maintain smaller class sizes, better facilities, and more consistent teacher attendance (Tooley et al., 2010). These structural features may enable more effective microsystem interactions. Teachers may provide more individualized attention in a class of 25 than in a class of over 60 students, regardless of their qualifications.

Recent research in developing countries confirms that teaching quality is associated with student achievement patterns, with institutional context informing the mediating role. The significant difference within-group emphasizes the need to avoid simplistic school-type determinism. Some public schools achieve strong outcomes while some private schools perform poorly (Härmä, 2013). School-type labels serve as proxies for complex clusters of features. The critical question is not whether public or private management proves inherently superior, but what specific characteristics are associated with effective chemistry education, a question that this study's focus on student perceptions rather than objective institutional measures cannot fully address.

Beyond Achievement Gaps

While the public-private achievement gap confirms well-established patterns (Härmä, 2013; Tooley et al., 2010), these specific trends warrant deeper interpretive attention than the statistics alone convey. Within this study, teachers' characteristics are as perceived by students rather than observed teachers' qualities. Students who perceive their teachers as enthusiastic, relatable, approachable, and knowledgeable achieve better than classmates who perceive teachers less favorably, even within the same schools and presumably the same classrooms. This merits consideration; students may accurately perceive genuine teacher quality variations. Although all students share the same teachers, they may experience teaching differently based on their position in classroom social hierarchies or their level of prior engagement. Higher-achieving students may perceive teachers more favorably because success generates positive attributions, making the correlation partly ambiguous. Furthermore, student engagement may independently influence both achievement and teacher perceptions. Distinguishing among these explanations requires designs that measure teacher quality independently of student perception, a methodological advance the current study cannot achieve.

Teacher Characteristics as Potential Proximal Processes

The significant correlation between teacher characteristic perceptions and achievement (r = .346) is consistent with Bronfenbrenner's (1979) emphasis on proximal processes, the reciprocal interactions through which learning occurs (El Zaatari & Maalouf, 2022). Teachers mediate between curriculum and student engagement, transforming abstract concepts into meaningful learning when conditions allow. Hattie's (2009) synthesis placed teacher-related variables among the top contributors to learning outcomes, a conclusion reinforced by López-Martín et al. (2023) whose estimate of 9 percent explained variance closely matches this study's 12 percent. In the Nigerian chemistry context, teacher qualification and teaching method have been identified as significant predictors of student performance (Cleopas & Onwuchekwa, 2024; Omwirhiren & Ibrahim, 2016), a pattern this study's teacher characteristics correlation affirms at the students' perception level. EST further suggests that teacher effectiveness depends on environmental supports provided by outer systems. For instance, teachers with deep CK may achieve different outcomes (Asaki & Adu-Gyamfi, 2025) depending on class size, material availability, and curricular mandates (Kang & Keinonen, 2018). Jerrim et al. (2025) confirms that teacher self-efficacy shows mixed direct effects on student outcomes, with effectiveness varying by contextual factors. Student perception in this study reflects teachers' enthusiasm, clarity, and perceived mastery, observable manifestations of PCK and instructional repertoire that Shulman (1987) and Ball et al. (2008) identified as foundational of effective teaching rather than assessing teacher knowledge or observed practice directly. This limits mechanistic interpretation but reflect dimensions of teacher-student interaction that matters for learning.

The Learning Environment Perception Pattern

The null relationship between perceived learning environment and achievement ($r = -.023$, $p = .368$) appears inconsistent with Fraser's (2012) cross-national evidence of positive associations. However, this finding aligns with EST in two ways, when interpreted at the correct level of analysis. First, student-level analysis captured perception variance that is analytically independent from the between-school environmental variation that actually predicts achievement. Thus, environmental effects may operate at the school level, while the individual perception level shows a negligible association. Second, the null relationship shows that adaptive preference formation may weaken the correlation between perceived learning environment and achievement. Therefore, students in poorly resourced schools adjust expectations downward, rating inadequate environments positively relative to their limited reference points, while students in well-resourced schools maintain higher standards and rate superior environments as merely adequate. Udoh (2012) confirms that learning environment and chemistry achievement are mediated by resource utilization patterns and pedagogical approaches, indicating that environmental effects operate indirectly rather than through student perceptions alone.

Attitude-Achievement Pattern

The absence of a significant attitude-achievement correlation ($r = -.023$, $p = .368$) diverges from research documenting positive attitude-achievement relationships in science education (Osborne et al., 2003). Multiple factors may explain this. The attitude measure may have captured general science enjoyment rather than productive attitudes, such as epistemic curiosity or persistence, that more directly drive achievement. When curricula emphasize rote memorization for high-stakes examinations, achievement depends primarily on sustained effort and effective study strategies rather than on genuine interest (Jegede, 2007). Musengimana et al.'s (2021) review of research on chemistry attitude aligns with the finding that teacher characteristics and quality of learning environment were more consistently associated with chemistry outcomes than student-level attitudes. These suggest that structural factors may carry more explanatory weight than affective ones in examination-driven systems. From an ecological perspective, highly motivated students may face constraints in converting positive attitudes into achievement in schools where laboratories are absent and instructional materials remain scarce.

Theoretical Considerations

Taken together, these patterns challenge individualistic explanations attributing achievement primarily to student characteristics such as motivation or ability. While equally cautioning against simple environmental determinism, physical resources alone do not guarantee learning. The more productive analytical question, how outer-system structures enable or constrain the microsystem processes through which learning occurs, requires the longitudinal and hierarchical designs identified in the Limitations section.

This study extends the validation of well-established public-private achievement gaps in Nigerian education in specific ways. The study is among the few Nigerian chemistry studies to examine microsystem variables (teacher characteristics, learning environment perceptions) and an exo-system variable (school type) within a single theorized ecological framework, moving beyond the single-factor analyses that have characterized most prior work. Furthermore, this study adds to international research on how ecological factors associated with science achievement in low- and middle-income countries are distinct when compared to the effect magnitudes and operational mechanisms in high-income countries (Praetorius et al., 2024).

The study reveals that ecological deprivation can affect the measurement instruments used in a study. Our study findings show a major misalignment with the EST microsystem assumption. The data collected on perceptions are limited to what the students experience; they are not in a position to provide information on a well-equipped learning environment. What they report as adequate may, in objective terms, represent significant deprivation. Therefore, research on science learning environments within low-resource contexts cannot treat student perception as bias-free when considering ecological conditions. This is because these perceptions are products of students' conditions. Furthermore, any theoretical framework that does not account for that complexity risks an adaptation problem.

Implications for Science Education Equity

Beyond correlation and effect size, this study reveals the need for educational equity in resource-constrained contexts. The achievement gap documents a dual system in which chemistry students' learning outcomes depend overwhelmingly on their families' capacity to pay for private schooling rather than on their own capabilities or interests. This represents a failure of the public education system's fundamental mission.

From an ecological perspective, this inequity operates across system levels. At the microsystem level, public school students experience larger class sizes, less supported teachers, and fewer learning materials. At the exo-system level, resource allocation policies systematically underfund public schools while regulatory frameworks permit private alternatives that serve those who can pay. At the macrosystem level, societal acceptance of this two-tiered system reflects broader patterns of inequality and limited commitment to educational equity as a public good. Addressing the chemistry achievement gap requires interventions operating across teacher training at the microsystem level, school privatization at the exo-system level, and reexamining how Nigerian society organizes, finances, and values chemistry education for all students.

Limitations

The fundamental limitation of this cross-sectional design is the non-random assignment of school types. Students attending both private and public schools are influenced by SES, parental education, educational values, and access to resources, which independently predict academic outcomes (Lubienski & Lubienski, 2014). However, research in developing countries documented that selection effects and differences in institutional quality and home environment operate simultaneously (e.g., Chudgar & Quin, 2012; Härmä, 2013). The observed 10.81-point achievement gap ($d = 2.14$) in this study reflects pre-existing differences between student populations rather than any institutional effect. Our study did not determine which factors account for observed differences without baseline achievement data, longitudinal tracking, or controls for family background. Future research must consider longitudinal designs that follow students from school entry, tendency score matching, or regression controls for SES and prior achievement, or natural experiments exploiting lottery-based school assignment.

A related conceptual limitation is the analytical level of the learning environment. Our study proposed examining the effects of the learning environment on achievement. However, our analysis examined student-level correlations between individual perceptions and achievement ($N = 1{,}500$) rather than school-level relationships between environmental quality and outcomes ($N = 47$). The student-level null correlation indicates that within schools, students who perceive their environment more positively underachieve compared to classmates with less positive perceptions, which is analytically distinct from whether schools with better environments achieve better overall outcomes. Investigating this requires hierarchical linear modeling (HLM) that partitions variance at the student and school levels. HLM would account for clustering, partition variance at student and school levels, and allow investigation of cross-level interactions. The current study did not employ multilevel modeling because the school-level sample ($N = 50$ schools) and the cross-sectional, single-district design were conceived prior to the analytical priority being established, and the available software environment at the point of analysis could not support the convergence requirements of full HLM with the observed cluster sizes. This is acknowledged as a significant methodological limitation that future studies should remedy. With a large sample ($N = 1{,}500$), statistically significant effects may also lack practical significance; readers should prioritize effect sizes over p-values when interpreting findings.

Sampling only Education District IV in Lagos State limits generalizability to other Lagos districts, other Nigerian states, rural or less-developed regions, and other African contexts. Lagos represents Nigeria's most economically developed area with a substantial private school sector. Patterns may differ in contexts with various levels of economic development, infrastructure quality, and public-private school distributions.

While Bronfenbrenner's (1979) EST guided the study as an interpretive framework, only microsystem variables (teacher characteristic perceptions, perceived environment) and exo-system variables (school type) were measured. Mesosystem variables, such as home-school connections, and macrosystem variables, such as educational policies and cultural values, were not assessed, limiting the capacity to test ecological predictions about cross-level interactions. Operationalizing the four systems in the EST framework would strengthen future studies.

Implications

The following implications assume that observed school-type differences partly reflect institutional quality rather than solely student selection effects, an assumption our design did not establish. If selection effects predominate, then interventions targeting school characteristics may prove ineffective because they address symptoms rather than root causes.

Research implications

Future research should employ longitudinal designs to examine developmental trajectories and use growth curve modeling to test whether teacher characteristics influence achievement growth rates. HLM would partition variance at student, classroom, and school levels while accounting for nested data structures, as demonstrated in recent developing country research (Praetorius et al., 2024). Structural equation modeling could test whether school-type effects operate through teacher quality, resources, class size, or instructional time. Qualitative research examining teacher and student experiences would clarify how environmental factors translate into daily practice. Replication studies across diverse geographic contexts would establish generalizability and identify universal versus context-specific patterns.

Practice implications

If future research confirms that teacher characteristics causally contribute to achievement differences, chemistry teachers would benefit from sustained professional development that emphasizes pedagogical content knowledge, facilitates student-centered instruction, and develops locally appropriate laboratory activities. Professional learning communities that examine student work collaboratively would be more effective than isolated workshops. Schools should strengthen teacher support through mentoring, provision of adequate instructional materials, and collaborative planning time. Retention of experienced, qualified teachers should be prioritized, given their significant associations with performance (Cleopas & Onwuchekwa, 2024), requiring attention to working conditions, professional support, and career development.

Policy implications

The achievement gap resulting from institutional differences or selection effects requires understanding of the role of educational equity in chemistry education. If future research establishes how institutional quality contributes to this gap. Governments must increase funding for facilities, instructional materials, teacher compensation, and professional development, accompanied by accountability mechanisms ensuring resources translate into improved conditions. Minimum standards should specify laboratory equipment, reasonable class sizes, adequate instructional time, and teacher qualification requirements. Educational equity initiatives must operate across ecological levels: teacher development, infrastructure improvements, community engagement, and accountability systems that provide support rather than sanctions. These recommendations extend to chemistry education contexts globally, where resource disparities and institutional inequities constrain learning opportunities.

CONCLUSION

In investigating the reason for poor performance in Chemistry, our study shows a significant association between school type, students' perceptions of teacher characteristics, and their learning outcomes. Private school students demonstrated substantially higher achievement than public school students (d = 2.14). While teacher characteristic perceptions showed a moderate positive correlation with achievement (r = .346). There was no significant relationship between students' perceptions of the learning environment and attitudes toward chemistry and achievement.

This cross-sectional design study with non-random school assignment prevents causal claims about school-type differences and student-level analyses. The study examined individual perception-achievement relationships rather than school-level environmental effects. Future research employing longitudinal designs, hierarchical modeling, and appropriate controls for selection bias is required before confidently establishing causal claims or policy recommendations. Within these interpretive constraints, the findings align with the microsystem and exo-system levels of the EST framework, which suggests nested environmental contexts warrant investigation through stronger research designs. The substantial achievement gap associated with school type and the moderate teacher characteristics indicates a potential need for intervention, although causal mechanisms remain uncertain. Questions about how EST factors interact over time, what mechanisms mediate school-type effects, how resource-constrained schools can implement effective pedagogy, and which teacher characteristics matter most in different contexts all require investigation through stronger research designs.

Ultimately, this research affirms education's fundamentally social and contextual nature. Learning occurs through participation in social practices shaped by institutional structures, resource allocations, and pedagogical relationships. Understanding and improving chemistry education requires examining the full ecological contexts within which students, teachers, and schools function (El Zaatari & Maalouf, 2022). Only through comprehensive, methodologically rigorous analysis can Nigeria and comparable nations design evidence-based interventions that promote equitable access to quality science education, a foundation essential for developing the scientifically literate citizenry that national development demands.

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Ethical statement: Institutional approval was obtained at two levels: a formal research authorization letter was secured from the Lagos State Ministry of Education, Secondary Education Management Board, Education District IV, and each school principal signed written consent confirming institutional willingness to participate prior to data collection. Given that the study involved minor participants (students under 18 years of age), consent forms were distributed to parents or guardians via the school one week before data collection. This form provided full description of the study's purpose, participant activities, voluntary nature of involvement, and confidentiality protections. The consent from the education district and individual school principals served as the primary ethical oversight mechanism, as no university-affiliated institutional review board was operationally required for district-level survey research under current Nigerian educational research practice. Students were further informed in plain, age-appropriate language about the study's purpose, the voluntary nature of participation, and their right to skip any item or withdraw at any point without penalty. No incentives were offered for participation, and no individual-level identifying data were collected. Instead, codes and numbers (1 for public school and 2 for private school) were used to identify the various participating schools and students. These procedures are consistent with ethical standards for educational research and applicable Nigerian research ethics guidelines.

AI statement: Grammarly was used for grammar check, spelling correction, and readability of the manuscript text. Ideas, analyze data, and substantive content draft were not generated using the tool. All output was reviewed and edited by the authors, who took full responsibility for the final text.

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