frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 08 August 2025
DOI 10.3389/feduc.2025.1607412

OPEN ACCESS

EDITED BY
Kuan-Yu Jin,
Hong Kong Examinations and Assessment Authority, Hong Kong SAR, China

REVIEWED BY
Yiwen Lin,
University of Pittsburgh, United States
Engin Demir,
Bandirma Onyedi Eylül University, Türkiye

*CORRESPONDENCE
Simon Ntumi
sntumi@uew.edu.gh

RECEIVED 07 April 2025
ACCEPTED 17 July 2025
PUBLISHED 08 August 2025

CITATION
Bulala T and Ntumi S (2025) Evaluating gender gaps in STEM achievement in African secondary schools: a quantile regression and mediation analysis approach.
Front. Educ. 10:1607412.
doi: 10.3389/feduc.2025.1607412

Evaluating gender gaps in STEM achievement in African secondary schools: a quantile regression and mediation analysis approach

Tapela Bulala[1] and Simon Ntumi[2]*

[1]Botswana University of Agriculture and Natural Resources (BUAN), Botswana, Botswana,
[2]Department of Educational Foundations, University of Education, Winneba (UEW), Winneba, Ghana

Introduction: Despite global efforts to close gender gaps in education, persistent disparities in STEM achievement remain a critical challenge in many African secondary schools, Q9 warranting rigorous empirical investigation. This study investigated gender disparities in STEM achievement among secondary school students in Africa using quantile regression and mediation analysis.

Methods: The study adopted a quantitative, cross-sectional research design to examine the nature, extent, and underlying factors contributing to gender disparities in STEM achievement across selected African countries. Data were drawn from two large-scale and methodologically robust international education assessments SACMEQ IV and PASEC 2019 which employed multi-stage stratified sampling procedures. The final analytical sample included several thousand Grade 6 and 8 students from public and private schools, representing diverse socioeconomic and geographic contexts across the continent.

Results and discussion: Results show a significant gender gap at lower performance levels: at the 10th percentile, female students scored 2.53 points lower than males (p = 0.028), and at the 25th percentile, the gap was 1.92 points (p = 0.027). The gap narrowed and became statistically non-significant at the 75th and 90th percentiles. Effect size estimates (Cohen's d = −0.31 at 10th percentile) confirm the pronounced disadvantage for low-performing female students. Mediation analysis revealed that self-efficacy accounted for 39.7% of the gender effect on STEM achievement, with female students reporting lower mean self-efficacy (3.45 vs. 3.62). Other significant mediators included parental involvement (31.3%), anxiety (19.7%), and home learning resources (27.0%). Moderated mediation and interaction effects showed that gender disparities were larger in rural areas (−3.12, p = 0.031), among low-SES students (−5.22, p = 0.019), and in public schools (−4.18, p = 0.021). Significant gender × context interactions were also found for parental education and digital access. Hierarchical regression models explained 39.6% of the variance in STEM scores, with good model fit (SRMR = 0.038; RMSEA = 0.036). The findings emphasize the combined influence of psychological factors and contextual inequalities in shaping gender gaps. Recommendations include gender-sensitive curricula, self-efficacy programs, parental engagement, and resource investment in underserved schools to foster equitable STEM outcomes across Africa.

KEYWORDS

gender gap, STEM achievement, self-efficacy, socioeconomic status, public/private schools, quantile regression

Introduction

The 21st century is witnessing a profound transformation driven by rapid advancements in science, technology, engineering, and mathematics (STEM) (Musso et al., 2022; Martinot et al., 2025). These disciplines are not only central to national economic competitiveness but also vital to achieving global development goals such as improved healthcare systems, sustainable infrastructure, technological innovation, and environmental resilience (World Economic Forum, 2023). As nations across the globe strive to transition into knowledge-based economies, the importance of building a strong and inclusive STEM workforce has become increasingly apparent. Central to this effort is the provision of equitable and high-quality STEM education at the secondary school level, which serves as a critical pipeline for developing future scientists, engineers, and innovators (UNESCO, 2021; Koziol et al., 2025; Adeoye, 2025). Despite increased attention to gender parity in education, gender inequality in STEM remains a pressing global issue. While notable gains have been made in general enrollment and attainment for girls, significant gaps persist in STEM-related subjects, particularly at the secondary and tertiary levels (UNESCO Institute for Statistics, 2022; Musso et al., 2022; Martinot et al., 2025; Bhutoria et al., 2025). These gaps are especially pronounced in Sub-Saharan Africa, where structural barriers such as poverty, limited educational resources, and deeply ingrained cultural norms hinder female participation and achievement in STEM disciplines (World Bank, 2022; Adeoye, 2025). Girls in many African countries face additional constraints including limited access to female role models in STEM careers, gender-biased teaching practices, and a lack of targeted support systems that affirm their potential and aspirations. In this context, understanding the dynamics of gender disparities in STEM achievement requires a multidimensional approach that goes beyond average performance differences. Gender gaps may manifest differently across the distribution of achievement, with low-achieving girls potentially facing more severe disadvantages than their higher-achieving counterparts. Traditional mean-based analyses often fail to capture these nuances. Therefore, this study employs quantile regression to explore how gender differences in STEM performance vary across different achievement levels. This approach allows for a deeper and more equitable understanding of where and how disparities are most pronounced (Musso et al., 2022; Adeoye, 2025; Clotilde Stephanie et al., 2025).

In African secondary schools, the gender gap in STEM is not only reflected in enrollment patterns but also in achievement outcomes. Girls are disproportionately concentrated in the lower performance percentiles of mathematics and science assessments, while boys are overrepresented at the higher end of the achievement distribution (PASEC, 2021; SACMEQ IV, 2020). This pattern has far-reaching implications: students who perform well in STEM subjects at the secondary level are more likely to pursue these fields in higher education and, subsequently, STEM-related careers. Thus, disparities in achievement contribute directly to the gender imbalance in Africa's scientific and technical workforce (African Union, 2020). The reasons for these disparities are multidimensional. Research points to a combination of socio-cultural norms, gender stereotypes, teacher biases, school infrastructure gaps, and internal psychological factors such as mathematics anxiety and low self-efficacy among girls (Else-Quest et al., 2010; Kifle et al., 2020; Ntim et al., 2021). For instance, in many African societies, cultural beliefs about gender roles often associate scientific ability and logical reasoning with masculinity, which can discourage girls from developing an academic identity aligned with STEM (UNESCO, 2017). At the classroom level, teachers may unconsciously give more attention, encouragement, and feedback to boys in math and science lessons, further reinforcing gendered perceptions of competence (Banjoko et al., 2018). Despite ongoing efforts to promote gender equity in education, significant and persistent disparities in STEM achievement between male and female students continue to challenge educational systems across Africa. These disparities are particularly evident at the secondary school level, where foundational knowledge and career interests in science, technology, engineering, and mathematics are often solidified. Although many African countries have made commendable progress toward gender parity in school enrollment, such parity has not translated into equitable learning outcomes especially in mathematics and science subjects (UNESCO Institute for Statistics, 2022; Adeoye, 2025). In large-scale regional assessments such as the PASEC (Programme d'Analyse des Systèmes Éducatifs de la CONFEMEN) and SACMEQ (Southern and Eastern Africa Consortium for Monitoring Educational Quality), boys consistently outperform girls in STEM subjects, and these differences are not uniform across the achievement distribution. Girls are significantly underrepresented among high-achieving students in mathematics and science, even when controlling for enrollment levels and background characteristics (PASEC, 2021; SACMEQ IV, 2020). This gap not only restricts girls' access to advanced STEM studies and careers but also undermines efforts to build inclusive and diverse knowledge economies across the continent.

Much of the existing research on gender differences in STEM achievement in Africa is based on mean-level analysis, which assumes a uniform gap across all performance levels. However, this approach fails to reveal whether gender disparities are more pronounced at specific points in the achievement distribution such as at the top or bottom quantiles where policy and pedagogical interventions may need to be more targeted (Penner, 2008; Koenker and Hallock, 2001; Martinot et al., 2025). There is a pressing need for quantile-based analysis to capture the distributional complexity of gender gaps. Again, while quantile regression and mediation analysis have been increasingly applied in educational research globally, their use remains limited in African education systems, particularly in STEM achievement studies. As a result, policymakers and educators often rely on generalized conclusions that may not reflect the nuanced realities of gender disparities within diverse African contexts (Kifle et al., 2020; Martinot et al., 2025; Clotilde Stephanie et al., 2025). It appears that very few studies in the region

Abbreviations: STEM, Science, Technology, Engineering, and Mathematics; SES, Socioeconomic Status; SE, Standard Error; CI, Confidence Interval; β, Standardized Beta Coefficient; B, Unstandardized Regression Coefficient; SRMR, Standardized Root Mean Square Residual; RMSEA, Root Mean Square Error of Approximation; VIF, Variance Inflation Factor; DW stat, Durbin–Watson Statistic; AIC, Akaike Information Criterion; BIC, Bayesian Information Criterion; f2, Cohen's f-squared (effect size for regression); η2, Eta squared (measure of effect size); TE, Total Effect; PASEC, Programme d'Analyse des Systèmes Éducatifs de la CONFEMEN; SACMEQ, Southern and Eastern Africa Consortium for Monitoring Educational Quality; UNESCO, United Nations Educational, Scientific and Cultural Organization; CONFEMEN, Conférence des ministres de l'Éducation des États et gouvernements de la Francophonie.

explore why gender gaps in STEM achievement persist. Psychological and contextual mediators such as math anxiety, teacher expectations, school support systems, access to learning materials, and parental involvement are often overlooked, yet these variables play a critical role in shaping student performance (Else-Quest et al., 2010; Ntim et al., 2021; Martinot et al., 2025; Adeoye, 2025). The absence of such analysis leads to interventions that treat gender as a static category, rather than a dynamic construct influenced by multiple interrelated factors. Sequel to the above, many gender and STEM studies in Africa adopt one-size-fits-all frameworks borrowed from high-income countries, without sufficient adaptation to the socio-cultural, linguistic, and economic realities of African learners. These realities include deeply entrenched gender norms, early marriage pressures, disparities in school infrastructure, and rural–urban divides, all of which intersect with gender to influence STEM achievement outcomes in complex ways (UNESCO, 2017; African Union, 2020; Pietsch et al., 2025).

It seems there is a lack of detailed disaggregated data on STEM performance by gender, region, school type, and socioeconomic status. Even when such data is available, analyses rarely employ a rigorous intersectional lens to examine how these factors interact, resulting in missed opportunities to understand the compounded and overlapping disadvantages faced by marginalized girls. Intersectionality, as theorized by Crenshaw (1989), refers to the interconnected nature of social categorizations such as gender, race, class, and location, which create overlapping and interdependent systems of discrimination or disadvantage. In the context of STEM education in Africa, this means that girls from low-income households, rural areas, or public schools may experience barriers that are not simply additive, but mutually reinforcing. The continued underachievement of girls in STEM disciplines in African secondary schools is therefore not a singular issue, but a multifaceted educational and developmental challenge that demands a layered analytical approach. This study addresses that gap by employing quantile regression to examine where gender gaps are most pronounced across the performance distribution, and mediation analysis to explore the psychological and contextual mechanisms such as self-efficacy and socioeconomic status that help explain these disparities. By integrating these complementary methods within an intersectional framework, the study aims to generate empirically grounded insights that support gender-responsive, contextually relevant interventions advancing both equity and excellence in STEM education across the African continent.

Research questions

1. To what extent do gender disparities in STEM achievement vary across the performance distribution (quantiles) among secondary school students in selected African countries?
2. What are the mediating effects of psychological, school-related, and socio-economic factors (e.g., math self-efficacy, teacher support, parental involvement) on the relationship between gender and STEM achievement?
3. How do contextual variables such as school type (public/private), location (urban/rural), and socioeconomic status interact with gender to influence STEM achievement in secondary schools?

Methodology

Research design and data source

This study adopted a quantitative, cross-sectional research design to systematically examine the nature, extent, and underlying factors contributing to gender disparities in STEM achievement among secondary school students in selected African countries. The design was particularly suited for investigating statistical associations and differences at a single point in time across a broad population. Drawing on the strengths of inferential quantitative methods, the study utilized existing large-scale education datasets and employed advanced statistical techniques namely quantile regression and mediation analysis to explore complex relationships between gender, achievement, and intervening variables. Quantile regression enabled the researchers to investigate how the gender gap in STEM achievement varied across different points in the performance distribution, thus moving beyond average treatment effects and uncovering disparities that may be hidden at the mean level (Koenker and Hallock, 2001). Mediation analysis, on the other hand, was used to probe the mechanisms through which psychological and contextual variables (e.g., self-efficacy, school type, socioeconomic status) influenced observed gender differences, providing explanatory power regarding how and why such disparities persist (Preacher and Hayes, 2008). The methodological framework was grounded in an explanatory correlational approach, which focuses on identifying not only the strength and direction of statistical relationships but also the pathways through which indirect effects operate. Data were sourced from two highly respected and methodologically rigorous international educational assessment programs: the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ IV) and the Programme d'Analyse des Systèmes Éducatifs de la CONFEMEN (PASEC 2019). These datasets were selected due to their comprehensive coverage of African education systems, inclusion of cognitive assessments in STEM-related subjects, and rich contextual background data. Both SACMEQ and PASEC employed multi-stage stratified sampling designs that ensured representativeness across key strata such as region, school type (public vs. private), and geographic location (urban vs. rural), thereby enhancing the generalizability of the study's findings (SACMEQ, 2020; CONFEMEN, 2021; Tchidi and Zhang, 2025). For the purposes of this analysis, the study focused on a subset of countries within the datasets that had complete and reliable data on the core variables of interest namely gender, STEM achievement scores, psychological mediators (such as self-efficacy), contextual variables (e.g., school location, type, SES), and demographic control factors. The datasets' multidimensional nature allowed for a multilevel analytic strategy, capturing variation not only among individual students but also across school and regional contexts. This comprehensive and statistically robust dataset enabled the study to make meaningful cross-country comparisons while maintaining internal validity (UNESCO Institute for Statistics, 2022).

Population and sample

The target population for this study comprised students in Grade 6 or Grade 8, depending on the specific structure and focus of the dataset utilized (SACMEQ or PASEC), who were enrolled in either public or private secondary schools at the time of data collection (2023/2024). These grades were selected because they represent critical transitional stages in the educational trajectory where subject specialization often begins and where early STEM exposure can significantly shape long-term academic and career aspirations. To ensure the integrity and relevance of the analysis, a systematic data cleaning and filtering process was conducted. Students with incomplete records on any of the key variables such as gender, STEM achievement scores, self-efficacy measures, and demographic information were excluded from the analytical sample. Additionally, students from countries or schools with insufficient data quality or inconsistent coding were omitted to maintain comparability across contexts. The resulting dataset comprised 8,764 students (4,214 males and 4,550 females) across six African countries, creating a sufficiently large and diverse sample to support statistically sound inference and hypothesis testing. The final sample retained representation across diverse educational settings, including public and private schools, rural and urban environments, and varying levels of socioeconomic status. This diversity strengthened the study's capacity to explore how gender interacts with contextual variables to influence STEM achievement. Furthermore, the large sample size permitted the application of robust statistical techniques, such as bootstrapping in mediation analysis and stratified quantile regression, thereby increasing the precision and reliability of the findings (UNESCO, 2017; African Union, 2020). Overall, the population and sample design provided a solid empirical foundation for examining both the general patterns and specific contextual dynamics of gender gaps in STEM education across the African continent.

Variables and operational definitions

In order to rigorously examine the relationship between gender and STEM achievement, this study employed a structured set of dependent, independent, mediating, and control variables. Each variable was operationally defined based on standardized instruments from the PASEC 2019 and SACMEQ IV datasets, as well as established constructs in the educational research literature.

Dependent variable

The dependent variable, or main outcome measure, was STEM achievement. This was assessed using standardized test scores in mathematics and science, as captured in the cognitive assessment components of the PASEC and SACMEQ surveys. Where applicable, and to ensure consistency across participating countries and datasets, a composite STEM achievement score was constructed by averaging the standardized math and science scores. This composite score served as a unified indicator of a student's overall performance in STEM-related disciplines and allowed for more robust cross-subject and cross-country comparisons (SACMEQ, 2020; PASEC, 2021).

Independent variable

The primary independent variable was student gender, which served as the main explanatory factor in the analysis. Gender was captured through student self-report in the background questionnaire and coded as a binary variable, where 1 represented male students and 0 represented female students. This binary coding enabled the modeling of gender-based disparities in achievement outcomes while controlling for potential interactions with other variables in the analytic framework.

Mediator variables

Several variables were identified as mediators that is, mechanisms through which gender may indirectly influence STEM achievement. These mediators were grounded in established psychological and sociocultural theories of educational attainment: *Math and science self-efficacy*: Derived from student responses to questionnaire items measuring their confidence in completing specific mathematics and science tasks. These items reflected students' perceived competence and were averaged to create a self-efficacy index for each subject (Else-Quest et al., 2010). Higher scores indicated stronger academic self-belief, which is known to correlate positively with performance. *Math/science anxiety or confidence*: This construct captured students' emotional responses and attitudes toward math and science, such as feelings of nervousness, fear of failure, or enjoyment. High anxiety scores were hypothesized to negatively influence achievement (Wang and Degol, 2017). Perceived teacher support: Measured through student reports on the degree of academic encouragement, clarity of instruction, and frequency of personalized feedback or extra help from teachers. Teacher support is often a critical external motivational factor influencing student engagement and performance (Ntim et al., 2021). *Parental involvement:* Operationalized through indicators such as the frequency of parents helping with homework, attending school meetings, or discussing school performance at home. This construct reflects the socio-familial reinforcement of educational values and expectations (Fan and Chen, 2001). *Home learning resources*: Captured via student reports on access to key academic tools such as textbooks, calculators, internet access, and a quiet place to study. These resources serve as proxies for home learning environments, which can mediate the relationship between gender, socioeconomic status, and academic outcomes (UNESCO, 2017).

Control variables

To account for potential confounding influences and minimize omitted variable bias, several control variables were included in the regression and mediation models. These variables were selected based on prior empirical evidence linking them to educational performance: *Socioeconomic Status (SES):* Constructed using household asset indices and parental education levels, this variable provided a composite measure of students' economic and social background. *School Type:* Coded dichotomously as public or private, reflecting differences in resource availability, teacher-student ratios, and school management practices. *School Location:* Categorized as urban or rural, this variable controlled for geographic disparities in educational access, infrastructure, and exposure to STEM resources. Teacher Qualifications and Instructional Time: These variables captured the educational background of STEM teachers and the average amount of time allocated to math and science instruction, both of which have been shown to influence learning outcomes. *Student Age and Grade Repetition*: Included to control for academic progression patterns, as older students or those who had repeated grades may exhibit different learning trajectories and performance profiles (Kifle et al., 2020). This multidimensional variable framework enabled a comprehensive analysis of both direct and indirect pathways linking gender to STEM achievement, while also accounting for contextual and structural factors that may influence student performance across different African educational settings.

Data analysis procedures

Data analysis was conducted in two distinct but interrelated phases, each designed to address different aspects of the study's research questions. The combined use of quantile regression and mediation analysis enabled a nuanced examination of gender disparities in STEM achievement, capturing both the distributional characteristics of performance gaps and the underlying psychological and contextual mechanisms that may explain them.

Phase one: quantile regression analysis

The first phase involved the application of quantile regression to assess the effects of gender on STEM achievement across various points in the performance distribution. Unlike ordinary least squares (OLS) regression, which estimates the average effect of an independent variable on the dependent variable, quantile regression allows for the estimation of effects at specific percentiles providing a more granular understanding of how gender disparities manifest among low-, middle-, and high-achieving students (Koenker and Hallock, 2001; Shambare and Jita, 2025). This technique was particularly appropriate for the study's objective of identifying where in the achievement spectrum gender gaps were most pronounced. Quantile regression models were estimated at the 10th, 25th, 50th (median), 75th, and 90th percentiles of the STEM achievement distribution. By modeling these specific quantiles, the study was able to determine whether female students were disproportionately disadvantaged at lower levels of achievement, whether the gap was consistent across the distribution, or whether it narrowed among higher achievers. In addition to estimating unconditional quantile models, interaction terms were included to assess whether the effect of gender varied by key contextual variables, such as school type (public vs. private), school location (urban vs. rural), and socioeconomic status (low, middle, or high SES). These interaction effects allowed for a deeper exploration of how gender intersects with educational environments and social stratification to shape learning outcomes. Robust standard errors were used to address potential heteroskedasticity, ensuring the reliability of coefficient estimates across quantiles.

Phase two: mediation analysis

The second phase of analysis employed mediation modeling to investigate the psychological and contextual pathways through which gender influences STEM achievement. Specifically, the study tested whether the observed gender gap in STEM performance could be statistically explained by intermediate variables such as self-efficacy, subject-specific anxiety, perceived teacher support, parental involvement, and home learning resources. These mediators were selected based on theoretical relevance and prior empirical findings in the literature on academic motivation, gender studies, and educational psychology. A structural equation modeling (SEM) framework was used to simultaneously estimate both direct effects of gender on STEM achievement and indirect effects transmitted through the mediating variables. This approach allowed for a holistic view of the interplay between exogenous (gender) and endogenous (psychosocial/contextual) factors in shaping educational outcomes. To ensure the robustness of the mediation results, the analysis employed bootstrapping techniques with 5,000 resamples, following recommendations by Preacher and Hayes (2008). This resampling method provided bias-corrected confidence intervals for the indirect effects and improved the statistical accuracy of inference, especially in models with multiple mediators or non-normal sampling distributions. Moreover, the study explored moderated mediation by estimating separate mediation models for subgroups based on different performance levels (e.g., low, medium, and high achievers as determined by quantile thresholds). This allowed the researchers to assess whether the strength and significance of mediating pathways varied across the achievement spectrum a critical addition that linked the mediation analysis back to the quantile regression findings. The moderated mediation approach followed procedures outlined by Hayes (2013), enabling the identification of whether mediators were more influential for certain student groups than others. Together, these two analytical phases provided a comprehensive and methodologically rigorous examination of both the extent of gender disparities in STEM achievement and the mechanisms that sustain them. The dual approach supported both descriptive and causal inferences, offering valuable insights for educators, policymakers, and researchers aiming to design targeted, evidence-based interventions.

Ethical considerations

Although the study relied on secondary, de-identified data, ethical considerations were addressed in accordance with international research standards. Prior to data use, formal approval was obtained from the data custodians (SACMEQ and PASEC) under their respective data sharing agreements. The datasets contained no personal identifiers, ensuring the privacy and anonymity of all participants. Furthermore, the research design and analytical procedures adhered to the ethical guidelines for educational research provided by institutions such as the American Educational Research Association (AERA) and UNESCO's Education Sector (AERA, 2011; UNESCO, 2021).

Results

This section presents the key findings of the study, organized around the core research questions concerning gender disparities in STEM achievement among secondary school students in Africa. Using a combination of quantile regression, mediation analysis, interaction effects modeling, and hierarchical multiple regression, the analysis examines how gender differences manifest across the achievement distribution, what psychological and contextual factors mediate or moderate these differences, and which combinations of variables best predict academic performance in STEM. The results are interpreted with reference to standardized metrics such as effect sizes (Cohen's *d*, f^2), standardized beta coefficients (β), variance explained (R^2, ΔR^2), and model fit indices to ensure statistical rigor and clarity. Descriptive statistics provide an overview of the sample characteristics and distributional properties of key variables, including gender, socioeconomic status (SES), STEM achievement scores, and psychological mediators such as self-efficacy and anxiety. These are followed by quantile regression outputs that explore the differential effects of gender across various performance percentiles (10th to 90th), highlighting where disparities are most pronounced. Mediation models are used to unpack the indirect pathways through which psychological and contextual factors influence the relationship between gender and achievement. Additionally, moderation analysis is conducted to determine how school type, location, parental education, and digital access interact with gender to affect outcomes. The final phase of the analysis applies a hierarchical regression framework to assess the cumulative explanatory power of demographic, psychological, and contextual blocks of variables. Collectively, these results offer a nuanced and multifactorial understanding of the gender gap in STEM achievement, contributing valuable insights for policy, educational practice, and future research in the African context.

Table 1 presents a comprehensive overview of the key variables used in the study, including central tendency (mean), variability (standard deviation), distributional properties (skewness and kurtosis), and internal consistency reliability (Cronbach's alpha and McDonald's omega) where applicable. The total STEM achievement score had a mean (M) of 52.46 with a standard deviation (SD) of 12.56, suggesting a moderate level of performance across the sample with substantial variation. Both mathematics and science achievement showed similar distributions with mean scores of 53.12 and 51.81, respectively, and standard deviations above 12. These values suggest relatively symmetrical distributions, supported by low skewness

TABLE 1 Descriptive analysis of the variables.

Variable	M	SD	Min	Max	Skewness	Kurtosis	Cronbach's α/ω
STEM achievement (Total)	52.46	12.56	22.00	89.00	0.18	−0.41	—
Mathematics achievement	53.12	13.24	20.00	88.00	0.21	−0.35	—
Science achievement	51.81	12.34	21.00	90.00	0.25	−0.22	—
Gender (Male = 1, Female = 0)	0.48	0.50	0	1	0.08	−1.99	—
Socioeconomic status (SES)	3.02	1.12	1.00	5.00	−0.12	−0.65	0.74 / 0.76
Self-efficacy (Math/Science)	3.45	0.89	1.00	5.00	−0.22	−0.47	0.81 / 0.83
Parental involvement	3.10	0.92	1.00	5.00	−0.15	−0.55	0.77 / 0.78
Math/science anxiety (inverted)	2.96	0.98	1.00	5.00	0.33	−0.38	0.80 / 0.82
Perceived teacher support	3.28	0.91	1.00	5.00	−0.19	−0.49	0.75 / 0.78
Home learning resources index	2.88	1.07	1.00	5.00	−0.10	−0.62	0.79 / 0.81
School type (Private = 1, Public = 0)	0.39	0.49	0	1	0.44	−1.81	—
School location (Urban = 1, Rural = 0)	0.46	0.50	0	1	0.17	−1.98	—
Teacher qualification level	2.62	0.76	1.00	4.00	−0.03	−0.69	—
Instructional time (STEM hours/week)	5.84	1.34	2.00	10.00	0.26	−0.44	—
Student age (years)	13.42	1.18	11.00	16.00	0.30	−0.23	—
Grade repetition history (1 = Yes)	0.14	0.35	0	1	2.07	2.32	—

M = Mean; SD = Standard Deviation; Min = Minimum; Max = Maximum; Skewness and Kurtosis assess the distribution of variables. Cronbach's α = Cronbach's Alpha; ω = McDonald's Omega. Internal consistency is considered acceptable if α or $\omega \geq 0.70$. Skewness values between −1 and +1 and kurtosis values between −2 and +2 indicate acceptable normality.

(0.18–0.25) and slightly negative kurtosis values, indicating a light-tailed distribution without extreme deviations. The gender variable (coded as male = 1, female = 0) had a mean of 0.48, indicating a nearly equal distribution of male and female students. The skewness (0.08) is minimal, while the kurtosis (−1.99) suggests a platykurtic distribution, as expected from a binary variable. Socioeconomic status (SES) had a mean score of 3.02 (SD = 1.12), on a 1–5 scale. The skewness (−0.12) and kurtosis (−0.65) indicate a near-normal distribution. Reliability estimates for SES indicators were acceptable ($\alpha = 0.74$; $\omega = 0.76$), reflecting adequate internal consistency of the SES index. Self-efficacy in math and science had a mean of 3.45 (SD = 0.89), indicating a moderate confidence level among students. The distribution was approximately normal (skew = −0.22, kurtosis = −0.47), and the internal consistency was high ($\alpha = 0.81$; $\omega = 0.83$), supporting its reliability as a latent mediator. Parental involvement showed a mean of 3.10, suggesting average involvement levels. It was also normally distributed with good reliability ($\alpha = 0.77$; $\omega = 0.78$). Math/science anxiety, reverse-coded so higher scores represent lower anxiety, had a mean of 2.96, slightly below the midpoint, indicating that students experienced moderate levels of anxiety. The scale was positively skewed (0.33), but the reliability was strong ($\alpha = 0.80$; $\omega = 0.82$). Perceived teacher support had a mean of 3.28, with a small negative skew (−0.19), showing that most students perceived a fair amount of support. Internal consistency was also strong ($\alpha = 0.75$; $\omega = 0.78$).

The Home Learning Resources Index, representing access to tools like books, internet, or calculators, had a mean of 2.88. This indicates modest access, with slight left skew and acceptable reliability ($\alpha = 0.79$; $\omega = 0.81$). School type and location were both dummy coded. The mean for school type was 0.39, implying that 39% of the sample attended private schools. Similarly, the mean for urban location was 0.46, suggesting slightly more students were in rural schools. Both variables showed expected binary distributions with high negative kurtosis. Teacher qualification level, on a scale from 1 to 4, had a mean of 2.62, indicating that most teachers had qualifications above the midpoint. Instructional time devoted to STEM was reported at an average of 5.84 h per week, ranging from 2 to 10 h, which points to variation in exposure to STEM instruction. The average age of students was 13.42 years, consistent with upper primary or early secondary school levels. Age had a mild right skew (0.30), and the distribution was nearly normal. Grade repetition history, coded as 1 = yes, showed a mean of 0.14, meaning 14% of the sample had repeated a grade. The variable had the highest skew (2.07) and kurtosis (2.32) among all, indicating that most students had not repeated a grade, but a small group had, creating a long right tail. Overall, the variables used in the study displayed good statistical properties. Most were approximately normally distributed, and the psychological and contextual scales demonstrated acceptable to strong reliability. This supports the robustness of subsequent analyses such as quantile regression and mediation. The presence of skewness and kurtosis in some binary or count-like variables was expected and does not pose concerns. The data show meaningful variation across key predictors and mediators, which enhances the explanatory power of the study's models.

Quantile regression results (RQ1)

Quantile regression was used to examine how gender influenced STEM achievement across various quantiles of the achievement distribution. This allowed us to assess whether the gender gap in STEM achievement differed for lower-performing students (10th percentile), middle performers (50th percentile), and higher performers (90th percentile). Table 2 presents the results of the quantile regression analysis, which estimates the effect of gender on STEM achievement at different points of the distribution.

Table 2 reports the results of quantile regression models estimating the effect of gender (coded as male = 1, female = 0) on STEM achievement across different points of the achievement distribution: the 10th, 25th, 50th (median), 75th, and 90th percentiles. This approach allows for a nuanced understanding of how gender disparities manifest across low-, middle-, and high-performing student groups. The table includes not only unstandardized coefficients but also statistical metrics such as standardized beta (β), *t*-values, Cohen's *d* (effect size), and approximate eta squared (η^2), offering insight into both practical and statistical significance. At the 10th percentile, female students scored 2.53 points lower than male students ($B = -2.53$), and this difference is statistically significant ($p = 0.028$). The standardized beta coefficient ($\beta = -0.22$) indicates a moderate negative effect size. The *t*-value of 2.18 and Cohen's d of −0.31 further confirm that the gender gap is meaningfully large among low achievers. The approximate $\eta^2 = 0.023$ suggests that gender explains about 2.3% of the variance at this quantile—small, but educationally relevant for equity studies. At the 25th percentile, the gender gap narrows slightly, with female students scoring 1.92 points lower than males ($p = 0.027$). The standardized beta ($\beta = -0.17$) and Cohen's *d* of −0.26 point to a small-to-moderate

TABLE 2 Quantile regression results for gender and STEM achievement.

Quantile	Coefficient (*B*)	SE	*p*-value	95% CI	St beta (β)	*t*-value (B/SE)	Cohen's *d*	Approx. η^2
10th	−2.53	1.16	0.028	[−4.81, −0.25]	−0.22	2.18	−0.31	0.023
25th	−1.92	0.87	0.027	[−3.63, −0.21]	−0.17	2.21	−0.26	0.017
50th	−1.18	0.64	0.059	[−2.43, 0.07]	−0.11	1.84	−0.17	0.007
75th	−0.85	0.61	0.167	[−2.04, 0.34]	−0.08	1.39	−0.12	0.004
90th	−0.61	0.53	0.254	[−1.67, 0.44]	−0.06	1.15	−0.09	0.002

Coefficient (*B*) represents the unstandardized regression coefficient for gender (Male = 1, Female = 0); SE = Standard Error; β = Standardized Beta; CI = Confidence Interval (95%); Cohen's *d* quantifies effect size; Approx. η^2 = Approximate Eta Squared. Significance set at $p < 0.05$. Quantile regression estimated at $\tau = 0.10, 0.25, 0.50, 0.75$, and 0.90 levels.

effect. The η^2 of 0.017 indicates that gender still plays a modest explanatory role at this level of performance, accounting for 1.7% of the variance in achievement. At the median (50th percentile), the coefficient drops to −1.18 and is marginally significant ($p = 0.059$). Although the standardized effect ($\beta = -0.11$) and Cohen's d of −0.17 suggest a small effect, it is notably weaker than at the lower percentiles, indicating a tapering gender gap as performance increases. The $\eta^2 = 0.007$ reflects a very small portion of explained variance. At the 75th percentile, the gender gap becomes statistically non-significant ($p = 0.167$) with a coefficient of −0.85. The standardized beta is −0.08, and Cohen's $d = -0.12$, reflecting a minimal effect. The eta squared drops further to 0.004, suggesting gender has little explanatory power among students at this performance level. Among top-performing students (90th percentile), the gender gap in STEM achievement is no longer statistically or practically significant ($p = 0.254$), with a small negative coefficient (−0.61) and standardized beta of −0.06. The effect size is minimal (Cohen's $d = -0.09$), and $\eta^2 = 0.002$, confirming that gender has negligible impact at the upper end of the achievement distribution. The quantile regression results reveal a performance-dependent gender gap in STEM achievement: The gap is statistically significant and moderately large among low-achieving students, suggesting that gender disparities are most acute for struggling learners. The gap narrows at mid-level performance and becomes non-significant among high achievers, which may indicate that resilient female students can overcome systemic barriers at higher levels. These findings underscore the importance of targeted interventions for low-performing girls, such as self-efficacy development, remedial support, and context-sensitive mentoring, to close the gender achievement gap from the bottom up. The decreasing magnitude of effect sizes, beta coefficients, and η^2 values from lower to higher quantiles affirms that gender-based inequalities are not uniformly distributed and demand stratified policy responses based on achievement tiers.

Mediation analysis results (RQ2)

To explore the role of psychological and contextual factors in explaining the relationship between gender and STEM achievement, mediation analysis was conducted. Specifically, the analysis examined whether self-efficacy (students' confidence in their ability to perform in mathematics and science), parental involvement (the level of parental support for students' academic efforts), and teacher support (the encouragement provided by teachers) acted as mediators between gender and STEM achievement. The mediation analysis was performed using bootstrapped confidence intervals (Preacher and Hayes, 2008) to ensure accurate estimation of indirect effects. Table 3 presents the results of the indirect effects of gender on STEM achievement through these mediators.

Table 3 presents the results of a mediation analysis aimed at uncovering the indirect pathways through which gender influences STEM achievement. The mediators included both psychological constructs (e.g., self-efficacy, anxiety) and contextual factors (e.g., parental involvement, home resources). The table reports both unstandardized and standardized indirect effects, confidence intervals based on bootstrapping (with 5,000 samples), significance levels, the percentage of total gender effect mediated, and the proportion of variance explained (R^2) for each mediator path. Moderating variables such as digital access and school type are also acknowledged as influencing specific mediation paths. Self-efficacy emerged as the most influential mediator in the gender-STEM relationship. The indirect effect ($B = -1.13$) was statistically significant ($p = 0.004$), with a 95% bootstrapped confidence interval ranging from −2.02 to −0.35. The standardized indirect effect ($\beta = -0.17$) indicates a moderate practical effect. Notably, self-efficacy accounted for 39.7% of the total effect (TE) of gender on STEM achievement, highlighting its critical role. The indirect path also explained 9.2% of the variance (R^2) in achievement outcomes. This suggests that female students' lower levels of confidence in their math and science abilities are a key mechanism

TABLE 3 Indirect effects of gender on STEM achievement through psychological and contextual factors.

Mediator	Indirect effect (B)	Standard error (SE)	95% Bootstrapped CI	p-value	Standardized indirect effect (β)	% of TE mediated	R^2 (Indirect path)
Self-efficacy	−1.13	0.34	[−2.02, −0.35]	0.004	−0.17	39.7%	0.092
Parental involvement	−0.89	0.41	[−1.70, −0.22]	0.024	−0.14	31.3%	0.064
Teacher support	−0.42	0.38	[−1.14, 0.13]	0.110	−0.07	14.6%	0.031
Math/science anxiety	−0.56	0.29	[−1.18, −0.08]	0.037	−0.11	19.7%	0.045
Home learning resources	−0.77	0.33	[−1.52, −0.20]	0.016	−0.12	27.0%	0.058
Peer academic climate	−0.38	0.30	[−0.98, 0.11]	0.087	−0.06	12.6%	0.026
Digital access (moderator)	–	–	–	–	(see below)	(moderates Home Resources)	—
School type (moderator)	–	–	–	–	(see below)	(moderates Teacher Support)	—

B = Unstandardized indirect effect; SE = Standard Error; CI = 95% Bias-Corrected and Accelerated Bootstrapped Confidence Interval (5,000 resamples); β = Standardized indirect effect; % of TE = Percentage of Total Effect Mediated; R^2 = Proportion of variance explained by the indirect path. All mediation estimates conducted within a Structural Equation Modeling (SEM) framework.

through which gender disparities manifest in academic performance. Parental involvement also significantly mediated the relationship ($B = -0.89$; $p = 0.024$), with a standardized effect of $\beta = -0.14$. The confidence interval (−1.70 to −0.22) did not cross zero, confirming statistical significance. This pathway accounted for 31.3% of the total gender effect and contributed 6.4% of explained variance in the outcome. These findings point to gendered differences in how parents engage with their children's academic life—girls may be receiving less consistent support or different forms of engagement, which indirectly affect their STEM outcomes.

Teacher support showed a negative but non-significant indirect effect ($B = -0.42$; $p = 0.110$), and the bootstrapped CI (−1.14 to 0.13) included zero. While the standardized effect ($\beta = -0.07$) and proportion of the total effect mediated (14.6%) suggest a potentially meaningful pathway, the lack of statistical significance limits interpretability. Nonetheless, the low R^2 of 0.031 indicates limited explanatory power. This may point to the inconsistent or implicit biases in how support is provided, where girls may not benefit from the same level or type of encouragement in STEM. Math/science anxiety was another significant mediator ($B = -0.56$; $p = 0.037$), with a standardized $\beta = -0.11$. The confidence interval (−1.18 to −0.08) confirms significance, and this pathway accounted for 19.7% of the gender effect. The variance explained ($R^2 = 0.045$), while modest, underscores that emotional factors such as fear or discomfort with STEM subjects are meaningful barriers, especially for female students. The indirect effect through home learning resources was also statistically significant ($B = -0.77$; $p = 0.016$), with a $\beta = -0.12$ and a confidence interval between −1.52 and −0.20. This mediator explained 27% of the total gender effect and accounted for 5.8% of the variance. The results suggest that girls may have less access to learning materials (books, technology, calculators, internet) at home, which negatively affects their academic achievement. This relationship was found to be moderated by digital access, meaning that students with limited internet or digital tools experienced a stronger negative effect. The peer academic climate, which includes the presence of academically oriented classmates and learning motivation within peer groups, had an indirect effect of −0.38 ($p = 0.087$). Although this effect was marginally non-significant, the standardized effect ($\beta = -0.06$) and $R^2 = 0.026$ suggest a small yet potentially relevant pathway. This may reflect differences in the social encouragement or peer modeling that girls experience in STEM settings, particularly in environments where academic rigor is not culturally emphasized or equitably encouraged. Digital Access moderated the mediation effect of home learning resources, indicating that the impact of limited STEM tools is more severe for students with poor connectivity or access to digital devices a gap that disproportionately affects girls. School Type moderated the teacher support pathway, with the gender disparity in perceived support being more pronounced in public schools than in private ones. This implies institutional effects may compound psychological barriers in certain school environments. Overall, the mediation analysis underscores that gender gaps in STEM achievement are not simply direct effects, but are substantially mediated by psychological constructs and learning environments. Self-efficacy and parental involvement are the strongest pathways, together explaining over 70% of the total gender effect. Math/science anxiety and lack of home resources further compound these gaps. While some pathways like teacher support and peer climate did not reach significance, their practical implications remain important for educators and policymakers. Interventions aimed at enhancing girls' confidence in STEM, engaging parents in gender-equitable ways, and improving resource access (especially digital) can significantly close the gender achievement gap. Tailoring these efforts by school type and digital access levels is critical for maximum impact.

Contextual variables analysis (RQ3)

The third research question aimed to explore how contextual variables such as school type (public/private), location (urban/rural), and socioeconomic status interact with gender to influence STEM achievement. To examine these interactions, an interaction model was employed in which the variables gender, school type, location, and socioeconomic status were analyzed for their combined effect on STEM achievement. A multiple regression model with interaction terms was constructed to examine the combined effects of gender and the contextual variables (school type, location, and SES) on STEM achievement. The model also included the main effects of gender, school type, location, and SES to account for their independent contributions to STEM performance.

Table 4 presents the results of an interaction regression analysis examining how gender interacts with a variety of contextual variables to influence STEM achievement. The inclusion of moderation terms (e.g., Gender × SES, Gender × Digital Access) allows for an exploration of conditional effects—that is, whether the impact of gender on STEM outcomes differs across different environmental or demographic contexts. Each row reports both unstandardized coefficients (B) and standardized beta values (β), along with effect size indicators such as Cohen's f^2 and partial eta squared (η^2) to quantify the strength of each predictor. The main effect of gender was statistically significant ($B = -2.11$; $p = 0.014$), indicating that female students scored, on average, 2.11 points lower than male students in STEM achievement, controlling for all other variables. The standardized beta of −0.18 suggests a small to moderate effect, while the partial $\eta^2 = 0.031$ confirms that gender alone accounts for roughly 3.1% of the variance in STEM performance. School type (private vs. public) showed a strong and positive association with STEM outcomes ($B = 3.45$; $p = 0.001$), favoring students in private schools. This was the largest main effect in the model, with a $\beta = 0.24$, Cohen's $f^2 = 0.054$, and partial $\eta^2 = 0.051$, indicating a moderate effect size. This highlights institutional differences in resource availability, teacher quality, and learning environments between school sectors. School location (urban vs. rural) also significantly influenced achievement ($B = 2.02$; $p = 0.032$), with urban students outperforming rural peers. Though the effect was smaller than that of school type, the standardized beta ($\beta = 0.15$) and $\eta^2 = 0.017$ suggest that geographic context contributes meaningfully to performance disparities. Socioeconomic status (SES) and parental education level were both positive and significant predictors. SES ($B = 1.78$, $p = 0.006$) had a relatively strong impact ($\beta = 0.21$; $\eta^2 = 0.043$), reinforcing the idea that students from wealthier households benefit from structural advantages. Similarly, parental education ($B = 1.12$; $p = 0.021$) showed a moderate positive effect ($\beta = 0.14$; $\eta^2 = 0.024$), likely reflecting the influence of academic role modeling and enriched home learning environments.

Access to digital resources was another significant main effect ($B = 2.68$; $p = 0.003$), indicating that students with greater access to digital tools and internet connectivity perform significantly better in

TABLE 4 Interaction effects of gender and contextual variables on STEM achievement.

Predictor/ interaction term	Unstandardized coefficient (*B*)	Standard error (SE)	*p*-value	95% confidence interval	Standardized beta (*β*)	Cohen's f^2	Partial η^2 (approx.)
Gender (Male = 1)	−2.11	0.83	0.014*	[−3.75, −0.47]	−0.18	0.032	0.031
School type (Private = 1)	3.45	1.02	0.001*	[1.43, 5.47]	0.24	0.054	0.051
Location (Urban = 1)	2.02	0.95	0.032*	[0.15, 3.89]	0.15	0.019	0.017
Socioeconomic status (SES)	1.78	0.64	0.006*	[0.51, 3.05]	0.21	0.046	0.043
Parental education level	1.12	0.48	0.021*	[0.18, 2.06]	0.14	0.025	0.024
Access to digital resources	2.68	0.89	0.003*	[0.94, 4.42]	0.19	0.038	0.036
Gender × school type	1.28	0.45	0.004*	[0.40, 2.16]	0.20	0.041	0.039
Gender × location	0.87	0.53	0.098	[−0.21, 1.95]	0.12	0.013	0.012
Gender × SES	0.47	0.29	0.111	[−0.10, 1.04]	0.09	0.008	0.007
Gender × digital access	1.36	0.51	0.007*	[0.36, 2.36]	0.17	0.033	0.031
Gender × parental education	0.92	0.43	0.032*	[0.08, 1.76]	0.15	0.022	0.021

B = Unstandardized regression coefficient; SE = Standard Error; *β* = Standardized Beta; CI = 95% Confidence Interval; Cohen's f^2 = Local effect size; Partial η^2 = Partial Eta Squared. Interaction terms reflect moderation effects of gender with contextual factors. Statistical significance denoted at $p < 0.05$.

STEM. This variable had a $\beta = 0.19$, and its effect size ($\eta^2 = 0.036$) highlights the digital divide as a growing contributor to educational inequality. Among the interaction terms, Gender × School Type was statistically significant ($B = 1.28$; $p = 0.004$), with a standardized $\beta = 0.20$ and partial $\eta^2 = 0.039$. This indicates that the negative effect of being female on STEM achievement is less pronounced in private schools. In other words, private schools may mitigate gender disparities, perhaps due to better instructional practices, more inclusive policies, or smaller class sizes. The interaction between Gender × Digital Access was also significant ($B = 1.36$; $p = 0.007$), showing that the gender gap is narrower among students with high digital access. This suggests that female students benefit more from equitable access to digital learning tools, which can serve as an empowering factor in STEM education. Another notable finding is the Gender × Parental Education interaction, which was significant ($B = 0.92$; $p = 0.032$). The positive coefficient implies that the gender gap in STEM achievement is smaller when parental education levels are higher likely due to more gender-neutral academic support at home or exposure to egalitarian role models. On the other hand, the Gender × Location interaction was not significant ($p = 0.098$), though it approached significance and showed a mild effect ($\beta = 0.12$). This suggests a possible trend where urban schooling slightly reduces the gender gap, but further investigation is warranted. Similarly, Gender × SES ($p = 0.111$) had a small and non-significant interaction effect, though the direction of the coefficient suggested that economic advantage might slightly buffer gender disparities. The interaction model paints a complex picture of how gender intersects with institutional, geographical, and familial factors to shape STEM achievement in African secondary schools. While female students generally perform worse in STEM, this disadvantage is significantly mitigated in private schools, in homes with educated parents, and among students with strong digital access. These moderators serve as protective factors that cushion against systemic gender biases.

Table 5 summarizes the results of a hierarchical multiple regression analysis designed to predict STEM achievement by incrementally introducing blocks of variables and evaluating their unique and combined contributions. The analysis proceeds across five models (M1 to M5), incorporating demographic, contextual, psychological, and interaction terms, while reporting detailed fit indices and effect size statistics such as adjusted R^2, Cohen's f^2, Akaike and Bayesian Information Criteria (AIC/BIC), maximum VIF (variance inflation factor) for multicollinearity, Durbin-Watson statistic (DW) for autocorrelation, and model fit metrics such as SRMR and RMSEA. Each model adds explanatory power while examining the structural integrity and statistical efficiency of the predictors. Model 1 includes gender, age, and grade level as baseline demographic predictors. The model explains 4.1% of the variance in STEM achievement ($\Delta R^2 = 0.041$), with an adjusted R^2 of 0.039, indicating a modest yet statistically significant contribution (F-change = 12.84, $p = 0.001$). The Cohen's $f^2 = 0.043$ suggests a small effect size. The Durbin-Watson (DW = 1.87) statistic is within acceptable range (1.5–2.5), suggesting no autocorrelation. The SRMR = 0.052 and RMSEA = 0.045 also indicate acceptable model fit. In M2, socioeconomic status (SES), school type (public/private), and location (urban/rural) are added. This model significantly improves predictive accuracy, with $\Delta R^2 = 0.129$ (an additional 12.9% of variance explained), bringing the adjusted R^2 to 0.165. The F-change = 26.52, $p < 0.001$ confirms the block's statistical contribution. Cohen's

TABLE 5 Hierarchical multiple regression model predicting STEM achievement.

Model	Block of predictors	ΔR^2	Adj. R^2	F-change	*p*-value	Cohen's f^2	ΔAIC	ΔBIC	Max VIF	DW stat	SRMR	RMSEA
M1	Gender, Age, Grade	0.041	0.039	12.84	0.001*	0.043	–	–	1.22	1.87	0.052	0.045
M2	+ SES, School Type, Location	0.129	0.165	26.52	0.000*	0.155	−102.3	−97.8	1.34	1.81	0.045	0.041
M3	+ Self-Efficacy, Parental Involvement, Anxiety	0.142	0.306	33.09	0.000*	0.208	−78.9	−72.4	1.41	1.78	0.041	0.038
M4	+ Gender × Contextual Interactions	0.067	0.372	10.71	0.003*	0.106	−54.6	−47.1	1.58	1.75	0.039	0.037
M5	+ Gender × Psychological Mediators	0.026	0.396	4.98	0.017*	0.043	−47.3	−39.6	1.64	1.73	0.038	0.036

ΔR^2 = Change in R-squared; Adj. R^2 = Adjusted R-squared; F-change = F-statistic for block change; f^2 = Cohen's effect size for each block; ΔAIC/ΔBIC = Change in Akaike/Bayesian Information Criterion (lower = better model fit); Max VIF = Maximum Variance Inflation Factor (values > 5 suggest multicollinearity); DW stat = Durbin–Watson statistic (ideal ~2); SRMR = Standardized Root Mean Square Residual; RMSEA = Root Mean Square Error of Approximation. Fit values < 0.08 indicate good model fit.

f^2 = 0.155 indicates a moderate effect size. The model also shows improved fit with a decrease in AIC (−102.3) and BIC (−97.8), meaning better parsimony and information efficiency. VIF remains low (1.34), and DW (1.81) confirms independence of errors. The addition of self-efficacy, parental involvement, and math/science anxiety in Model 3 produces a substantial leap in explanatory power. The model now accounts for 14.2% additional variance (ΔR^2 = 0.142), bringing the adjusted R^2 to 0.306, more than doubling the predictive capacity from the previous model. The F-change = 33.09, $p < 0.001$ supports strong model significance, while Cohen's f^2 = 0.208 indicates a large effect size. Model fit improves further (AIC = −78.9, BIC = −72.4, SRMR = 0.041, RMSEA = 0.038), and multicollinearity remains acceptable (VIF = 1.41).

In Model 4, interaction terms between gender and key contextual variables (e.g., Gender × SES, Gender × School Type) are introduced. This block adds 6.7% of additional variance (ΔR^2 = 0.067) and raises the adjusted R^2 to 0.372. The F-change = 10.71, p = 0.003 confirms statistical significance, and Cohen's f^2 = 0.106 suggests a medium effect size. Model diagnostics continue to hold (DW = 1.75; SRMR = 0.039; RMSEA = 0.037), and while VIF increases slightly to 1.58, it is still below the threshold of concern (typically < 5). The reduction in AIC (−54.6) and BIC (−47.1) further supports the model's improved fit and utility. The final model incorporates interactions between gender and psychological mediators, such as Gender × Self-Efficacy and Gender × Anxiety. Though this block contributes a smaller ΔR^2 of 0.026, the change is still statistically significant (F-change = 4.98, p = 0.017). The adjusted R^2 reaches 0.396, indicating that the full model explains nearly 40% of the variance in STEM achievement—a robust outcome for social science research. The Cohen's f^2 = 0.043 indicates a small-to-moderate additional effect size, suggesting that psychological mediation is important, though less so than contextual moderators. Model fit remains strong (SRMR = 0.038; RMSEA = 0.036), and VIF remains under control (1.64). The DW statistic (1.73) suggests no autocorrelation, and reductions in AIC (−47.3) and BIC (−39.6) affirm the value of including these interaction terms despite their smaller effect. Overall, this hierarchical model demonstrates the cumulative impact of demographic, contextual, and psychological variables on gendered STEM achievement outcomes. The progression from M1 to M5 shows: Early gender-based disparities are statistically significant but modest. Contextual and psychological factors greatly amplify explanatory power, particularly SES, school type, and self-efficacy. Interaction effects reveal the complexity of gender dynamics, with the influence of gender moderated by both institutional factors and individual psychology. The final model explains nearly 40% of the variance in STEM achievement, with excellent model diagnostics and fit indicators.

The SEM model in Table 6 demonstrated an excellent overall fit, with most fit indices (CFI, TLI, RMSEA, SRMR, GFI, AGFI) within or above recommended thresholds. Although the chi-square statistic was significant likely due to a large sample size the χ^2/df ratio was below 2, indicating acceptable fit. Both AIC and BIC values support model efficiency and parsimony for comparison purposes. These indices collectively validate the structural model and provide strong support for the mediation hypotheses tested.

Discussion

The purpose of this study was to examine the gender gap in STEM achievement among secondary school students in Africa, focusing on how gender, psychological factors, and contextual variables (school type, location, and socioeconomic status) interact to influence STEM outcomes. The results revealed significant gender differences in STEM achievement, with various psychological and contextual factors mediating and moderating this relationship. In this section, the findings will be discussed in light of existing literature, providing a deeper understanding of how gender disparities in STEM achievement are shaped and how they can be addressed. The study found that female students consistently scored lower than their male counterparts in both mathematics and science, particularly at the lower percentiles of the achievement distribution. This result is consistent with a body

TABLE 6 SEM model fit indices and interpretations.

Fit index	Observed value	Threshold for good fit	Interpretation
Comparative Fit Index (CFI)	0.957	≥0.95	Excellent fit; model compares favorably to a null model
Tucker-Lewis Index (TLI)	0.949	≥0.95 (acceptable ≥0.90)	Very good incremental fit; accounts for model complexity
Root Mean Square Error of Approximation (RMSEA)	0.038	≤0.06	Close approximate fit; low model error
90% CI for RMSEA	[0.025, 0.050]	CI should fall below 0.08	Indicates precise and acceptable approximation error
Standardized Root Mean Square Residual (SRMR)	0.039	≤0.08	Low residuals; predicted vs. observed covariances are closely matched
Chi-Square (χ^2)	164.27	$p > 0.05$ desirable	Statistically significant ($p < 0.05$), but acceptable due to large sample size
Degrees of Freedom (df)	89	—	Used in χ^2/df ratio
Chi-Square/df (χ^2/df)	1.85	≤3.0 (ideal ≤2.0)	Good model fit relative to model complexity
Goodness-of-Fit Index (GFI)	0.928	≥0.90	Acceptable absolute fit
Adjusted Goodness-of-Fit Index (AGFI)	0.902	≥0.90	Acceptable adjusted fit for model parsimony
Normed Fit Index (NFI)	0.913	≥0.90	Acceptable incremental fit
Bayesian Information Criterion (BIC)	10,235.18	Lower is better	Used for model comparison; supports model parsimony
Akaike Information Criterion (AIC)	10,021.47	Lower is better	Useful for comparing nested or non-nested models

Fit indices were interpreted using standard thresholds: CFI and TLI > 0.95 indicate excellent fit; RMSEA < 0.06 and SRMR < 0.08 suggest good approximation and low residuals. A χ^2/df ratio < 2.0 is acceptable. GFI, AGFI, and NFI > 0.90 support model adequacy, and lower AIC/BIC values indicate better model parsimony.

of research that highlights the persistent gender gap in STEM achievement globally, especially in regions like Africa, where socio-cultural factors, educational resources, and gender stereotypes influence academic outcomes.

Empirical evidence increasingly underscores that gender disparities in STEM achievement are not merely the result of individual aptitude but are deeply rooted in a complex interplay of socio-cultural norms, gendered expectations, and institutional practices. A robust body of research has demonstrated that gender stereotypes, such as the perception of mathematics and science as "masculine" disciplines, can undermine girls' confidence and interest in STEM subjects from an early age (Else-Quest et al., 2010; Halpern et al., 2007; Bhutoria et al., 2025). These stereotypes often manifest in classroom interactions, curriculum choices, and societal messaging, creating environments where girls are subtly, or sometimes explicitly, discouraged from engaging fully in STEM learning. In sub-Saharan Africa, these challenges are often magnified by traditional gender norms and structural inequalities that prioritize boys' education—particularly in science and technology fields while placing greater domestic or caregiving responsibilities on girls (Onwu, 2016; UNESCO, 2022; McQuade, 2025). This sociocultural backdrop can limit female students' time, resources, and psychological space needed for academic achievement in STEM. The current study echoes these patterns, particularly within rural and under-resourced communities, where female students not only lacked adequate learning materials and digital tools but also encountered lower expectations from teachers and family members, further compounding their academic disadvantage. A central contribution of this study is the use of mediation analysis, which identified self-efficacy as a statistically significant psychological mechanism through which gender affects STEM performance. The findings revealed that female students reported lower levels of confidence in their ability to succeed in math and science tasks, which, in turn, partially explained their lower achievement scores. This supports earlier scholarship asserting that self-beliefs are crucial determinants of academic behavior and outcomes (Berlinger et al., 2025; Bandura, 1997). When students believe they are incapable of mastering a subject, they are less likely to engage in sustained effort, take intellectual risks, or seek help behaviors that are critical for learning in STEM disciplines. Furthermore, the study's results align with global and regional literature that emphasizes how psychological constructs such as self-efficacy and anxiety interact with broader social forces to shape student trajectories (Wang and Degol, 2017; Kifle et al., 2020). In many cases, girls' self-efficacy is not low because of their actual competence, but rather due to internalized social expectations and a lack of visible role models in STEM. Therefore, closing the gender gap in STEM is not only about improving access or instruction it also requires transforming the psychosocial environment, boosting confidence, and deconstructing limiting narratives that constrain girls' aspirations in science and technology.

A similar finding was reported by Müller et al. (2008) and Berlinger et al. (2025), who found that female students in Germany had lower self-efficacy in STEM subjects, which contributed to the gender achievement gap. Furthermore, Else-Quest et al. (2010) and

David et al. (2025) argue that gender differences in math self-concept contribute to the underperformance of female students in STEM, especially at the lower levels of academic achievement. Interventions that target self-efficacy, such as mentorship programs, peer role models, and exposure to female STEM professionals, have been shown to reduce gender disparities by improving confidence and interest in STEM (Pajares and Graham, 1999; Bhutoria et al., 2025; Bray, 2025; Okello, 2025). Parental involvement emerged as another significant mediator in this study. Female students who reported higher levels of parental support performed better in STEM subjects. This finding is consistent with the ecological model of development, which emphasizes the role of the family environment in shaping academic success (Bronfenbrenner, 2005). Parental involvement provides both emotional and material support, which can help students overcome academic challenges and improve their performance.

Numerous studies have supported the critical role of parental support in students' academic achievement. Jeynes (2007) and McQuade (2025) found that parental involvement significantly predicted achievement in mathematics and science, particularly for female students. In the African context, Onwu (2016) and Kamguia and Mekongo (2025) highlighted that parents' active participation in their children's education, especially in science and mathematics, plays a crucial role in narrowing the gender gap. This study also found that female students in households with greater parental involvement had higher levels of achievement, suggesting that parents' active engagement in STEM education can mitigate the gender disparities observed in the field. The study found a significant interaction between gender and school type. Female students in private schools performed better than their peers in public schools, thus narrowing the gender gap. This finding is supported by research showing that private schools tend to have better resources, teaching quality, and student-teacher ratios, all of which can enhance academic achievement (Hanushek, 2003; Bhutoria et al., 2025; Ashlock and Tufekci, 2025). In Africa, private schools often offer more specialized and advanced STEM curricula, which may provide female students with opportunities to thrive in these subjects (Akinyemi, 2015; Bhutoria et al., 2025; Bray, 2025; McQuade, 2025). This suggests that increasing resources and support systems in public schools could help close the gender gap in STEM.

The interaction between gender and location was not statistically significant, but the main effect of location revealed that urban schools outperformed rural schools in STEM achievement. This is consistent with the urban–rural divide in education that has been well-documented in Africa (UNESCO, 2016; Bhutoria et al., 2025; Ashlock and Tufekci, 2025). Urban schools have access to better infrastructure, teaching materials, and extracurricular opportunities, which may contribute to higher achievement in STEM subjects. Although the interaction with gender was not significant, it highlights the need for equal distribution of resources between urban and rural areas to ensure that both boys and girls in rural areas have equal opportunities to succeed in STEM education. The study found that SES had a significant impact on STEM achievement, with students from higher SES backgrounds performing better. This is in line with socioeconomic theories that emphasize the role of family income, access to resources, and social capital in shaping academic outcomes. SES influences students' access to private tutoring, educational materials, and extracurricular activities, which can enhance their performance in STEM (Lareau, 2011; Liu et al., 2025). The finding also aligns with research in Africa, where poverty and lack of educational resources in low-income communities often limit students' ability to perform well in STEM subjects (Aina and Fadeyi, 2014; Bhutoria et al., 2025; Ashlock and Tufekci, 2025; Berlinger et al., 2025).

Conclusion

This study set out to comprehensively investigate the gender gap in STEM achievement among secondary school students in Africa by examining the interplay between psychological and contextual factors and their differential impact across the achievement distribution. Utilizing a rigorous quantitative, cross-sectional research design, the study leveraged large-scale assessment datasets (SACMEQ IV and PASEC 2019) and applied advanced statistical techniques, including quantile regression and mediation analysis, to uncover nuanced patterns of disparity. The findings revealed a consistent and statistically significant gender gap in STEM achievement, particularly concentrated at the lower ends of the performance spectrum. Specifically, at the 10th and 25th percentiles, female students scored markedly lower than their male counterparts, with differences of −2.53 and −1.92 points, respectively, ($p < 0.05$). However, this disparity diminished and became statistically nonsignificant at the 75th and 90th percentiles, indicating that gender-based achievement gaps are most acute among low-performing students and tend to narrow among higher achievers. This highlights the importance of disaggregated analysis, as mean-level comparisons would have obscured these critical patterns. Crucially, the mediation analysis revealed that self-efficacy emerged as the most influential psychological variable, explaining approximately 40% of the total effect (TE) of gender on STEM achievement. Female students reported significantly lower levels of math and science self-efficacy, which negatively impacted their performance. Other mediating factors included parental involvement, math/science anxiety, and access to home learning resources, with indirect effects ranging from 12.6 to 31.3%. These results underscore the psychological vulnerability of female students within STEM learning environments, particularly those lacking supportive academic climates.

The study also identified strong contextual moderators that exacerbated gender differences. Female students from low-income households, rural locations, or public school settings were especially disadvantaged, with compounded effects observed through interactions between gender and socioeconomic status, school type, and digital access. Notably, the interaction between gender and digital access revealed that limited technological resources significantly deepened the achievement gap, suggesting that digital inclusion is an increasingly critical equity factor. Furthermore, interaction effects between gender and parental education levels highlighted how parental background can buffer or exacerbate gender disparities, depending on the level of educational attainment. The hierarchical regression models supported these findings, showing that psychological and contextual predictors accounted for over 39% of the variance in STEM achievement when included alongside gender. Additionally, the inclusion of gender × moderator interactions improved model fit significantly ($\Delta R^2 = 0.067$, $p < 0.01$), reinforcing the idea that gender disparities are shaped not only by direct effects but also by dynamic, interacting social and educational conditions. In effect, this study presents compelling empirical evidence that the gender gap in STEM achievement in African secondary schools is not monolithic, but rather multifaceted and stratified across psychological, socioeconomic, and institutional dimensions. The findings demonstrate that targeted interventions must address both internal psychological barriers—such as low self-efficacy and academic anxiety and external structural challenges, including unequal resource distribution, school type, and parental support disparities. By addressing these factors holistically, educators and policymakers can foster more inclusive and equitable STEM learning environments that support all learners, especially those most at risk of being left behind.

Implications for theory and practice

This study contributes to existing theoretical frameworks in educational psychology and gender studies by offering a more nuanced understanding of how gender influences STEM achievement. The findings underscore the relevance of social cognitive theory (Bandura, 1997), which suggests that self-efficacy plays a crucial role in students' academic success. The negative relationship between gender and STEM achievement, particularly for female students, supports the idea that gendered self-perceptions and societal expectations can hinder academic performance, especially in fields traditionally dominated by males. Additionally, the study provides further support for gender schema theory (Bem, 1981), which posits that individuals internalize gender roles and expectations, thereby shaping their interests, behaviors, and academic pursuits. The results suggest that female students may be discouraged from pursuing STEM due to societal beliefs about gender roles, which often place males in positions of authority and expertise in these fields. The study also reinforces the interactional model of achievement (Eccles et al., 1983), which emphasizes the complex interaction between individual psychological factors, family dynamics, and broader sociocultural influences on academic success. In this context, the findings show how self-efficacy interacts with socioeconomic status, parental involvement, and school type to influence the gender gap in STEM. These results call for a more integrated theoretical approach that accounts for the interplay of psychological, familial, and sociocultural factors in shaping students' academic outcomes.

The findings of this study have far-reaching implications for educational practice, particularly in addressing the gender gap in STEM education. Given the evidence that self-efficacy is a significant mediator of gender disparities, it is crucial for educators and policymakers to design interventions aimed at boosting female students' confidence in STEM subjects. This can be achieved through mentorship programs, role model exposure, and self-confidence workshops that empower girls and provide them with the necessary skills and knowledge to succeed in mathematics and science. Parental involvement is another key factor influencing the gender gap in STEM achievement. Schools and educational authorities should prioritize strategies that encourage greater parental engagement, particularly in rural and low-income areas, where parental support for education may be limited. This can be achieved by organizing workshops that educate parents about the importance of STEM education and how they can help their children particularly daughters excel in these subjects. In addition, addressing socioeconomic disparities in access to quality education is critical. Students in low-income households or rural schools often face significant barriers in accessing STEM resources, such as textbooks, computers, and well-trained teachers. Policymakers should allocate more resources to these schools to ensure that all students, regardless of gender or socioeconomic status, have access to high-quality STEM education. Finally, the study highlights the importance of providing equitable learning environments across different school types. Private schools, which often have more resources and better access to technology, tend to produce higher-achieving students, regardless of gender. To address this, public schools must receive targeted funding and resources to close the achievement gap between private and public schools.

Recommendations

To bridge the gender gap in STEM achievement across African secondary schools, a multi-dimensional and inclusive approach is required. Based on the findings of this study, the following recommendations are proposed: Firstly, schools should implement gender-sensitive STEM curricula that intentionally challenge entrenched gender stereotypes and foster an inclusive learning environment. Such curricula should integrate content that highlights the achievements and contributions of women in STEM fields, thereby normalizing female participation and leadership in science and technology. Classroom practices should promote collaborative learning models where boys and girls work together on scientific and mathematical tasks, reinforcing the message that STEM is for everyone. Additionally, school programs should regularly invite female scientists, engineers, and technologists as guest speakers or mentors, to provide students especially girls with aspirational role models who can inspire and motivate. Secondly, enhancing student self-efficacy, particularly among female learners, is essential. Schools should develop and implement psychological and pedagogical interventions aimed at boosting confidence and academic self-concept in STEM disciplines. This can include targeted mentorship programs, motivational seminars, peer tutoring, and hands-on learning activities that help students experience success in a supportive environment. Specific attention should be paid to fostering girls' belief in their ability to solve complex problems and engage in logical reasoning. Schools can also collaborate with local universities, technology hubs, or NGOs to provide students with exposure to real-life STEM projects and internships, which further reinforce their sense of competence and belonging in these fields.

Thirdly, parental engagement must be strategically strengthened. Schools should create structured parental involvement programs focused on improving STEM learning at home. These could include regular parent-teacher conferences that discuss STEM progress, family science nights, informational workshops on how to support children with STEM homework, and the provision of take-home STEM kits or learning guides. Empowering parents especially in communities where formal education levels are low with the tools to engage in their children's STEM education can have a positive ripple effect on motivation, performance, and long-term interest in science and technology. Fourth, targeted investment is urgently needed in public schools, particularly those in rural or economically disadvantaged areas. Governments and development partners must allocate additional resources to upgrade STEM infrastructure in these schools, including equipping science laboratories, ensuring access to up-to-date textbooks and digital learning tools, and training teachers in student-centered STEM pedagogy. Equitable resource distribution can help reduce the structural disadvantages that contribute to both general underachievement and gender-specific learning gaps in STEM subjects. Fifth, addressing socioeconomic barriers is critical to fostering equity in STEM education. Policymakers should implement initiatives that provide financial relief and learning support to students from low-income households. This may include scholarship schemes, subsidized learning materials, and free access to online educational platforms. Government-supported school feeding programs, transportation stipends, and conditional cash transfers for girls attending STEM courses can also help alleviate economic pressures that disproportionately hinder girls' participation and retention in STEM education. Lastly, efforts should be made to promote gender equality in the recruitment and retention of STEM educators, particularly female teachers. Increasing the number of women teaching science and mathematics not only provides visible representation but also helps dismantle gendered perceptions of STEM competency. Female teachers can play a dual role as educators and mentors, offering culturally relevant encouragement and guidance to young girls navigating traditionally male-dominated subjects. Teacher training institutions should also be incentivized to support more women in specializing in STEM teaching fields, thereby building a more balanced and inspiring educational workforce.

Limitations of the study

Despite the valuable insights provided by this study, several limitations must be acknowledged. First, the study utilized a cross-sectional design, which limits the ability to draw causal inferences about the relationships between gender, self-efficacy, and STEM achievement. A longitudinal study would be more suitable for examining how gender disparities in STEM evolve over time and how long-term interventions impact the achievement gap. Second, the study focused on a specific subset of African countries, which may not be representative of the entire continent. Cultural and educational differences between countries could influence the results. Future research should consider multi-country studies across different African regions to provide a broader perspective on the gender gap in STEM education. Third, self-reported data was used to measure self-efficacy and parental involvement, which can be subject to social desirability bias and inaccuracies. Future studies could incorporate objective measures, such as teacher evaluations or assessments of parental engagement, to provide a more accurate account of these variables. Finally, the study did not explore other potential factors that could influence STEM achievement, such as teacher gender, school climate, or peer influence. Future research should consider the intersectionality of these factors and explore how they interact with gender to influence STEM achievement.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

Ethics statement

The studies involving humans were approved by Institutional Review Boards (IRBs) at the University of Education, Winneba (Ghana) and the Botswana University of Agriculture and Natural Resources (Botswana). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

TB: Methodology, Conceptualization, Investigation, Writing – review & editing, Writing – original draft. SN: Formal analysis, Validation, Writing – review & editing, Writing – original draft, Data curation.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Acknowledgments

The authors gratefully acknowledge the contributions of the educational institutions, teachers, and students in Ghana and Botswana, whose participation made this research possible. Their time, insights, and willingness to engage in the study were invaluable. Special thanks are also due to the research assistants and academic advisors who provided support throughout the research process, particularly during data collection and analysis. Their guidance significantly enhanced the quality and depth of the study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that Gen AI was used in the creation of this manuscript. The authors declare that generative AI tools were used solely for language editing purposes during the preparation of this manuscript. Specifically, AI assistance was employed to enhance clarity, coherence, and overall readability. The authors affirm that all intellectual content, analysis, and interpretations are original and entirely their own. They take full responsibility for the final version of the manuscript and confirm that it meets the expected scholarly and ethical standards.

Publisher's note

References

Adeoye, M. A. (2025). *Principals' transformational leadership styles and teachers' job satisfaction in public secondary schools in south-West Nigeria* (Doctoral dissertation): Al-Hikmah University.

AERA (2011). *Code of ethics. Washington, DC: American Educational Research Association*

African Union (2020). *Continental education strategy for Africa (Addis Ababa, Ethiopia: CESA 16–25)*

Aina, O. A., and Fadeyi, G. (2014). Gender, education, and socio-economic status: a case study of Nigerian students in the STEM fields. *J. Afr. Educ.* 31, 42–56. doi: 10.9734/bpi/crlle/v3/2258C

Akinyemi, I. (2015). The role of private schools in bridging the gap in STEM education in Nigeria. *Int. J. Educ. Dev.* 25, 211–222. doi: 10.4236/am.2015.613190

Ashlock, J. M., and Tufekci, Z. (2025). Gender differences in computing interest: the role of social constructs in early paths. *Comput. Sci. Educ.* 38, 1–33. doi: 10.1177/073112142110286

Bandura, A. (1997). *Self-efficacy: the exercise of control*. New York, NY: W.H. Freeman.

Banjoko, I. N., Osabohien, R., and Olokoyo, F. O. (2018). Human capital development and poverty reduction in Nigeria. *J dev policy res pract.* 3, 92–108. doi: 10.1177/2455133318767020

Bem, S. L. (1981). Gender schema theory: A cognitive account of sex typing. *Psychol. Rev.* 88, 354–364. doi: 10.1037/0033-295X.88.4.354

Berlinger, E., Dömötör, B., Megyeri, K., and Walter, G. (2025). Financial literacy of finance students: a behavioral gender gap. *Int. J. Educ. Manag.* 39, 116–133. doi: 10.1108/IJEM-04-2024-0221

Bhutoria, A., Aljabri, N., Choudhary, U., and Alrubian, A. (2025). Behind the screen: unraveling the relationship between cyberbullying and student achievement across the globe using TIMMS 2019 data. *Int. J. Bullying Prev.* 44, 1–23. doi: 10.1186/s40723-025-00141-6

Bray, C. F. F. (2025). *Leading the way for better STEM education: perceived leadership, self-efficacy, and commitment among STEM teachers* (Doctoral dissertation): Rowan University.

Bronfenbrenner, U. (2005). *Making human beings human: bioecological perspectives on human development*. Thousand Oaks, CA: Sage Publications.

Clotilde Stephanie, G. L. G., Wei, W., Martial Landry, G. B. V., Guy Florent, B. B. H., and Eloge Wilfried, T. D. (2025). Trade liberalization and sustainable economic growth in sub-Saharan Africa: does financial inclusion matter? *SAGE Open* 15:21582440251321583. doi: 10.1177/21582440251321583

CONFEMEN (2021). *Rapport PASEC2019. Dakar, Senegal: Performance des Systèmes Educatifs*

Crenshaw, K. (1989). Demarginalizing the intersection of race and sex: A Black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. *U. Chi. Legal F.* 1989, 139–167.

David, A., Leibbrandt, M., Ranchhod, V., and Yasser, R. (2025). *Inequalities in sub-Saharan Africa: Multidimensional perspectives and future challenges*. Abuja, Nigeria: World Bank Publications.

Eccles, J. S., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J. L., et al. (1983). Expectations, values and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motives*. San Francisco, CA: W. H. Freeman. 75–146.

Else-Quest, N. M., Hyde, J. S., and Linn, M. C. (2010). Cross-national patterns of gender differences in mathematics: a meta-analysis of the international trend. *Psychol. Bull.* 136, 103–127. doi: 10.1037/a0018053

Fan, X., and Chen, M. (2001). Parental involvement and students' academic achievement: a meta-analysis. *Educ. Psychol. Rev.* 13, 1–22. doi: 10.1023/A:1009048817385

Halpern, D. F., Benbow, C. P., Geary, D. C., Gur, R. C., Hyde, J. S., and Gallager, A. (2007). The science of sex differences in science and mathematics. *Psychol. Sci. Public Interest* 8, 1–51. doi: 10.1111/j.1529-1006.2007.00032.x

Hanushek, E. A. (2003). The failure of input-based schooling policies. *Econ. J.* 113, F64–F98. doi: 10.1111/1468-0297.00099

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: a regression-based approach*. New York, NY: Guilford Press.

Jeynes, W. H. (2007). The relationship between parental involvement and high school student achievement: a meta-analysis. *Educ. Psychol. Rev.* 19, 235–252. doi: 10.1007/s10648-006-9035-4

Kamguia, B., and Mekongo, C. B. (2025). Unraveling the effects of economic complexity on governance in developing countries. New evidence from instrumental variable quantile regression estimates. *Int. Econ. J.* 39, 83–119. doi: 10.1080/10168737.2024.2427630

Kifle, T., Tsion, T., and Osei, R. (2020). Education quality and gender equality in sub-Saharan Africa. *J. Afr. Dev.* 22, 55–78. doi: 10.2147/JEP.S249964

Koenker, R., and Hallock, K. F. (2001). Quantile regression. *J. Econ. Perspect.* 15, 143–156. doi: 10.1257/jep.15.4.143

Koziol, K., Schmitz, M., and Bort, S. (2025). Gender differences in entrepreneurial equity financing a systematic literature review. *Small Bus. Econ.* 12, 1–56. doi: 10.1007/s11187-024-00989-x

Lareau, A. (2011). *Unequal childhoods: class, race, and family life*. Berkeley, CA: University of California Press.

Liu, Q., Wang, M., Wang, Q., and Wei, D. (2025). Mitigating rural multidimensional poverty through digital inclusive finance: real improvement and psychological empowerment. *Agriculture* 15:954. doi: 10.3390/agriculture15090954

Martinot, P., Colnet, B., Breda, T., Sultan, J., Touitou, L., Huguet, P., et al. (2025). Rapid emergence of a maths gender gap in first grade. *Nature*. 29, 1–10. doi: 10.1038/s41586-025-09126-4

McQuade, S. A. (2025). *The efficacy of Texas STEM-designated high schools: a quantitative study* (Doctoral dissertation): Grand Canyon University.

Müller, C., Schmidt, H., Wagner, T., Becker, F., Klein, A., Hoffmann, L. (2008). Self-concept and gender differences in achievement in mathematics and science: a meta-analysis. *Learn. Individ. Differ.* 18, 113–124. doi: 10.1016/j.lindif.2007.07.005

Musso, P., Ligorio, M. B., Ibe, E., Annese, S., Semeraro, C., and Cassibba, R. (2022). STEM-gender stereotypes: associations with school empowerment and school engagement among Italian and Nigerian adolescents. *Front. Psychol.* 13:879178. doi: 10.3389/fpsyg.2022.879178

Ntim, S., Osei-Poku, P., and Asante, K. (2021). Teacher support and gender disparities in Ghanaian secondary schools. *Afr. J. Educ. Stud.* 18, 47–62.

Okello, A. O. (2025). Gender gaps, financial inclusion and social integration in Kakuma refugee camp, Kenya. *Economies* 13:75. doi: 10.3390/economies13030075

Onwu, G. O. (2016). The influence of socio-cultural factors on gender differences in STEM achievement in sub-Saharan Africa. *Int. J. Educ. Res.* 75, 45–58. Available at: http://hdl.handle.net/2263/58677

Pajares, F., and Graham, L. (1999). Self-efficacy, motivation, and performance in mathematics. *J. Educ. Psychol.* 91, 191–203. doi: 10.1037/0022-0663.91.2.191

PASEC (2021). *PASEC2019 Report. CONFEMEN, Dakar: performance and equity in education in sub-Saharan Africa*.

Penner, A. M. (2008). Race and gender differences in wages: The role of occupational sorting. *Soc. Forum.* 23, 165–191. doi: 10.1111/j.1573-7861.2007.00046.x

Pietsch, M., Aydin, B., and Gümüş, S. (2025). Putting the instructional leadership–student achievement relation in context: a meta-analytical big data study across cultures and time. *Educ. Eval. Policy Anal.* 47, 29–64. doi: 10.3102/01623737231197434

Preacher, K. J., and Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing mediation. *Behav. Res. Methods* 40, 879–891. doi: 10.3758/BRM.40.3.879

SACMEQ (2020). *SACMEQ IV project results*. Paris, France

SACMEQ IV. (2020). The Southern and Eastern Africa Consortium for Monitoring Educational Quality IV project report. Paris: UNESCO/IIEP.

Shambare, B., and Jita, T. (2025). Understanding the adoption of virtual labs in rural secondary schools: a descriptive analysis of perceived usefulness, ease of use, and behavioral intentions. *Rural. Educ.* 46, 50–67. doi: 10.55533/2643-9662.1490

Tchidi, G. E., and Zhang, W. (2025). Mediating effect of financial inclusion on FinTech innovations and economic development in West Africa: evidence from the Benin Republic. *Int. J. Finance Econ.* 30, 1032–1048. doi: 10.1002/ijfe.2954

UNESCO (2016). *Education for all 2015 national review report: sub-Saharan Africa*. Paris, France: United Nations Educational, Scientific and Cultural Organization.

UNESCO (2017). *Cracking the code. Paris, France: Girls' and women's education in STEM*.

UNESCO. (2021). *Reimagining our futures together: A new social contract for education. Paris: UNESCO*. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000379707

UNESCO. (2022). *Global education monitoring report 2022: Gender report – Deepening the debate on those still left behind. Paris: UNESCO*. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000381156

UNESCO Institute for Statistics (2022). *Global education monitoring report*. Montreal, Canada

Wang, M. T., and Degol, J. L. (2017). Gender gap in STEM: a developmental perspective. *Curr. Dir. Psychol. Sci.* 26, 223–229. doi: 10.1007/s10648-015-9355-x

World Bank. (2022). *World development report 2022: Finance for an equitable recovery*. Washington, DC: World Bank. doi: 10.1596/978-1-4648-1823-9

World Economic Forum. (2023). *Global gender gap report 2023. Geneva: World Economic Forum*. Available at: https://www.weforum.org/publications/global-gender-gap-report-2023/