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Concerning the status of mathematics and physics for secondary school science students' sustainability in the 21st century STEM disciplines

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Introduction: The National Examination Council of Tanzania plays a significant role in shaping secondary school graduates' career pathways through the Certificate of Secondary School Education (CSEE). This study examined future implications and strategies for improving graduates' prospects in Science, Technology, Engineering, and Mathematics (STEM) fields, using the 2022 CSEE results from secondary schools in Mbeya City.

Methods: The study analyzed data from 58 secondary schools in Mbeya City. Statistical tools, including tables, bar charts, and chi-square tests, were used to organize, analyze, and interpret the data.

Results: Out of approximately 7,900 students, about 19% were found to be eligible to pursue STEM-related careers, with nearly two-thirds originating from private schools. Approximately 500 girls participated in STEM subjects, with significantly higher participation from private schools; the number of participants from private schools was about four times that from public schools. Gender parity was observed in private schools, whereas boys outperformed girls in public schools. Physics recorded the lowest levels of both participation and performance, with approximately three times as many students from private schools as from public schools, despite the higher overall participation of public-school students in the CSEE. Mathematics and physics emerged as key enablers of STEM success.

Discussion: The findings highlight disparities in STEM participation and performance between public and private schools and underscore the critical role of subject selection in shaping STEM career pathways. It is therefore recommended that science students take both mathematics and physics in the CSEE, rather than the current practice in which mathematics is compulsory while physics remains optional.

KEYWORDS

21st century skills, chi-square test, CSEE, gender disparity, STEM studies

1 Introduction

The term Science, Technology, Engineering, and Mathematics (STEM) originated in the USA in the 2000s by the National Science Foundation through efforts to improve federal government science education (Dugger, 2010). In the 21st century, STEM, an acronym for Science, Technology, Engineering, and Mathematics, has gained global popularity, especially in the digital age of development (McDonald, 2016; Waite and McDonald, 2019). STEM jobs take into account professional and technical support careers in the field of computer science

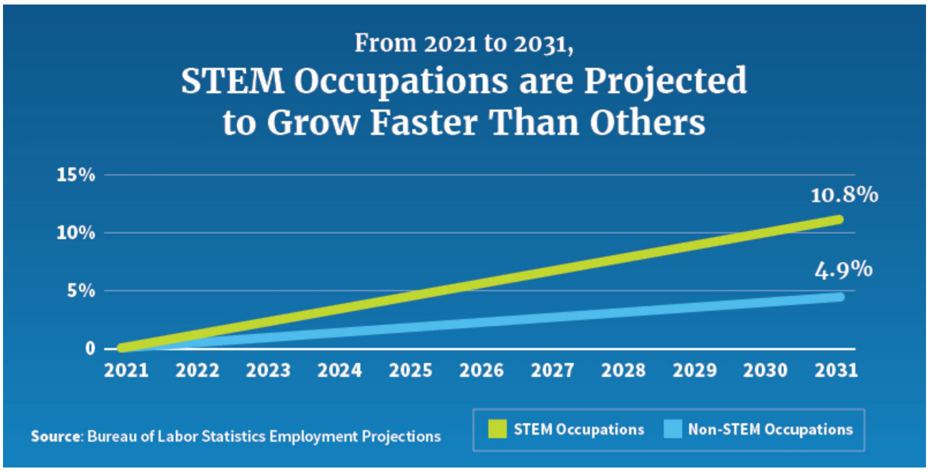

FIGURE 1
STEM jobs projections. Source: The US Bureau of Labor Statistics.

and mathematics, engineering, and life and physical sciences, but not limited to managerial professions (Drucker, 1976; Langdon et al., 2011).

In the 21st century, the STEM job market has been growing faster than the non-STEM job market. At the Bureau of Labor Statistics in the US, "In 2021, there were nearly 10 million workers in STEM occupations, and this total is projected to grow by almost 11% by 2031, over two times faster than the total for all occupations" (Carnevale et al., 2023), as depicted in Figure 1.

Moreover, Harris and Hodges (2018) suggested job market projections by 2020 in the United States suggested that non-STEM jobs were losing market share while biomedical engineering occupations took the lead, followed by other STEM jobs. A current STEM jobs projection set by Wales et al. (2023) following their study on future jobs from 2021 to 2031, suggest that STEM jobs will increase about twice (11%) as much as non-STEM (4.9%) jobs (Wales et al., 2023).

1.1 Empowering the young generation in STEM

The integration of sustainability into STEM education, particularly in primary and secondary schools, is crucial for nurturing a generation equipped not only to tackle environmental challenges (Nguyen et al., 2020) but also to prepare to take STEM jobs in the 21st century (Routray and Mohanty, 2024). Emphasizing physics and mathematics within this framework is essential, as it underpins many scientific principles and applications (Bao and Koenig, 2019; Galili, 2018). By fostering a sustainability mindset early on, science students can develop critical thinking and problem-solving skills necessary for future STEM careers (Okonkwo et al., 2024).

1.1.1 Importance of early education in sustainability

Early integration of sustainability within STEM education enables learners to grasp real-world environmental challenges while nurturing critical thinking and innovation (Routray and Mohanty, 2024). Engagement initiatives such as Youth@STEM4SF (Youth at STEM for Sustainable Future) further strengthen this connection by presenting physics through the lens of sustainable development, thereby boosting student interest and participation, especially among underrepresented groups (Gulejova, 2024).

1.1.2 Role of physics in STEM

Physics forms a foundational component of STEM education because it underpins understanding across multiple scientific disciplines, making its emphasis essential for developing comprehensive scientific literacy (Gulejova, 2023). Programs such as Eva the Engineer illustrate this role by showing how physics concepts can be applied to sustainability, engaging students in practical, hands-on learning experiences that help them grasp environmental challenges and their real-world implications (Klink et al., 2020).

While emphasizing that physics is important, it is equally crucial to acknowledge that mathematics underpins and strengthens students' understanding of physics concepts (Galili, 2018). Furthermore, maintaining a balanced focus across all STEM subjects helps provide a well-rounded education, better preparing learners to address a wide range of sustainability challenges (Noweir et al., 2024).

1.2 Public and private schools in Tanzania toward STEM sustainability

In the 19th century, the formal education schools emerged in three forms: public-owned and public-funded (government schools), private-owned but publicly funded (religious schools), and private-owned and private-funded schools (David et al., 2021), mostly intended for profit. After independence, Tanzania's education system adopted the same model of school ownership and funding (Wedgwood, 2007). In this context, privately owned but publicly funded schools (religious schools) and privately owned, privately funded schools are termed as private schools (Lassibille and Tan, 2001). The position of the school types is reflected in differences in funding, infrastructure, teacher supply, class size, and community support (Lawrent, 2020), shaping students' access to quality mathematics and physics instruction. These differences influence the sustainability of the national STEM pipeline by affecting who enters, stays, and succeeds in STEM pathways over time (Ochieng and Yeonsung, 2021). For instance, private schools usually have better-funded laboratories, equipment, and ICT access, which allows for practical physics experiments and applied math exercises that promote deeper learning and sustained interest in STEM (Lawrent, 2020). On the other hand, public schools with few laboratories find it difficult to offer comparable hands-on learning opportunities, which lowers long-term STEM retention to students (Semali, 2020). A situation is even worse in rural schools (Semali and Mehta, 2012).

STEM studies have been pointed out by many contemporary researchers as being behind the 21st-century skills (Gardner et al., 2018). The skills needed in the workforce in this era are associated with collaboration and communication, creativity and innovation, critical thinking, and problem solving (Ismail, 2018; Teo and Ke, 2014). Private schools come in because public schools were not able to accommodate the demand from the citizens (Heyneman and Stern, 2014). Nevertheless, the viability of private schools may be jeopardized due to their reliance on private finance, as these institutions are expected to demonstrate academic proficiency to attract student enrolment and hence increase financial support (Sahlberg, 2016). Furthermore, given that these institutions are not government-funded but controlled, certain governments may apply stringent limitations that could lead to their demise (Metzger, 2003). For example, private schools supported by the government in the USA were directed to enroll students according to the government's directions (Rose and Gallup, 2000). This may lead to parents not sending children to private schools, regardless of a reputable education (Yahl, 2015).

1.3 Gender, quality education, and sustainability in STEM

Since the establishment of the sustainable development goals (SDGs) by the United Nations (UN) in January 2016 (Gripenberg, 2017), efforts to ensure gender equity in STEM studies have strengthened globally (Buck et al., 2020). This follows a call for action to achieve the Fourth Sustainable Development Goal (SDG4), which defines quality education according to the UN (Edwards et al., 2024). Quality education (SDG4) aims not only to provide inclusive and equitable education, but also to promote lifelong learning opportunities (Avelar et al., 2019).

SDG4 ensures equitable access to quality STEM education, which is necessary for producing future scientists and engineers who will tackle sustainability challenges (Shahidul, 2020). Thus, quality education in STEM shall enhance sustainability, in this way enabling future professionals in STEM to address environmental and workforce challenges in the 21st century (Tytler, 2020). Moreover, gender equity ensures that the STEM pipeline is inclusive, diverse, and capable of sustaining long-term scientific and technological growth (Campbell et al., 2022).

While some regions of the world are closing gender gaps in STEM studies, like the USA and Europe, in Africa and some Asian countries, the gap-filling rate is the lowest (Kamberidou and Pascall, 2019; Loyalka et al., 2021). Emphasizing the importance of boosting STEM studies in the literature has centered on pedagogical skills, low teacher-student ratios, incompetent teachers, and the availability (Villegas, 1991). Moreover, girls' participation in STEM subjects during secondary school education, especially in Africa, is more associated with cultural practices and other reasons associated with masculinity (Archer et al., 2018). It was crucial to note that private schools in certain developing nations have demonstrated constant success, providing significant insights for overcoming the hurdles of student participation in STEM courses (Mbiti, 2016).

1.3.1 Gender in private schools in Mbeya city

Tanzania's education policymakers have taken a step aggressively by including the private sector in the running of schools alongside public schools (Samoff, 1990). However, the contribution that private schools have made to the overall education system has not been adequately acknowledged and recognized (Lassibille and Tan, 2001). An example of this would be the fact that private schools in Mbeya city of Tanzania, do not have any gender disparities in terms of academic performance (Kibona, 2023). This might be a huge step forward for many developing nations (Rieckmann, 2017). By highlighting the ability of private schools to address gender equality in education, which is an essential component of encouraging equitable access to quality education in the region, this achievement brings attention to the potential of private schools in enhancing gender equity in STEM. Figure 2 presents the performance of 32 private schools in Mbeya city and 26 public schools.

Not only did the private schools in Mbeya city resolve gender concerns, but they also increased students' performance, which made it possible for a considerable number of students to pursue studies in STEM fields for their future jobs (Figure 3). That is, about 1,284 (58%) of students in private schools pass rate was in the first and second division. On the other hand, fewer students about 1,055 (18% of public-school students) took the first and second division in public schools (Figure 2).

There is a correlation between the performance in first and second division and the performance STEM subjects. One of the strong reasons is that more subjects passed for students in higher division. For instance, consider students in biology, about 2028 (90%) of all students who attempted biology passed the subject in private schools, whereas about 3,311 (58%) of students passed biology in public schools (Figure 3). Basic mathematics performance had been continually deteriorating in time since the introduction of secondary schools (Kambuga, 2013). However, for the private schools in Mbeya city, this was not the case, as evidenced in 2022, about 1,181 (53%) of all students who sat the Certificate of Secondary School Education (CSEE) passed the basic mathematics. Conversely, performance in public school was about 1,021 (18%) of all candidates who sat for basic mathematics (Figure 3). Note that this percentage tallies with the percentage of students in the first and second division, particularly for public schools. Physics, being both the least opted-for and least performed, saw around 754 (13%) students pass physics in public schools, whereas approximately 810 (36%) passed physics in private schools. A last but more importantly record was the number of students who passed both mathematics and physics, 699 (about 12%) in public schools where boys were more than twice number of girls and around 776 (35%) in private schools with proportionally same number of boys and girls, respectively. It is important to note that almost all students opted and passed physics (13%) also passed mathematics (12%).

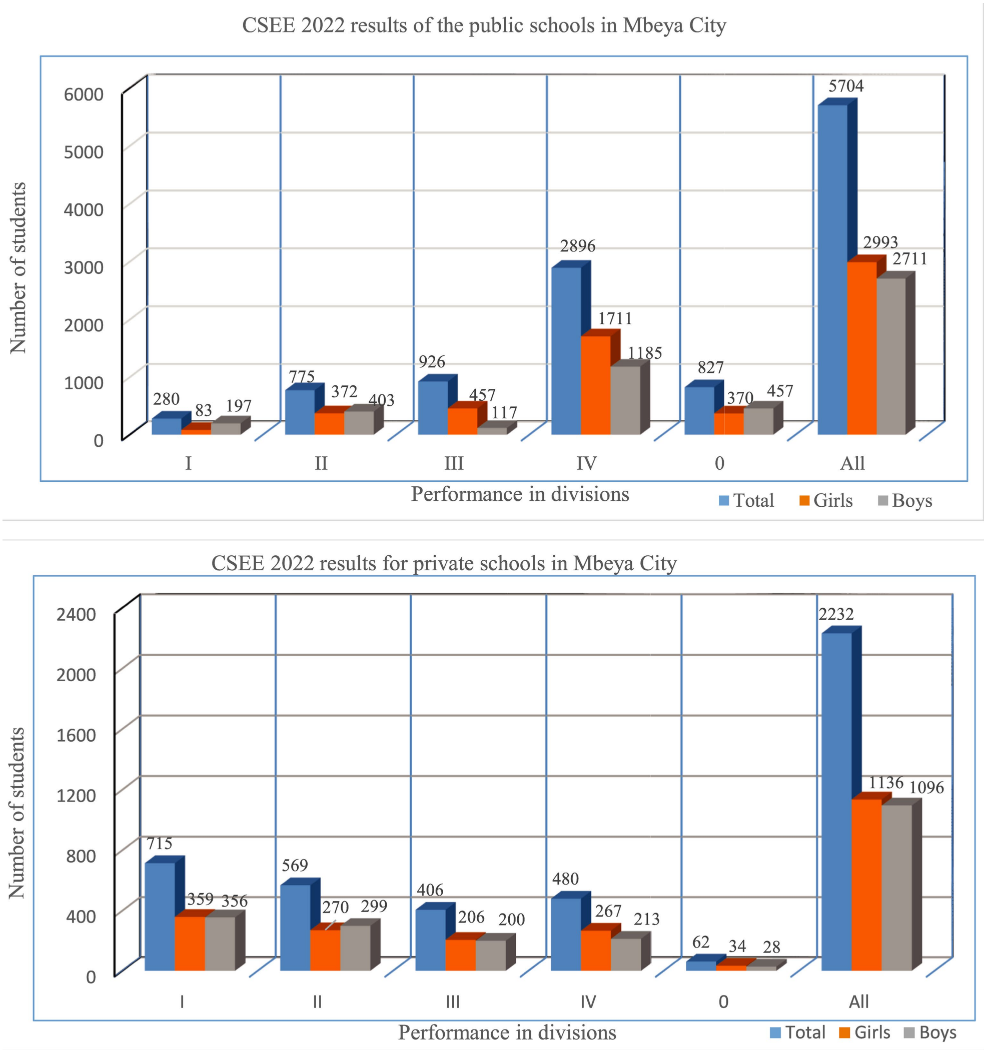

FIGURE 2
CSEE 2022 results in Mbeya city in divisions.

The point of this study is not only to show how physics is different from other STEM subjects, but also to show how mathematics is especially important in physics. The goal is to let education policymakers and other interested parties know that mathematics and physics should be treated as separate and unique when promoting STEM to secondary students. This goes against the present trend in promoting STEM/ science in secondary schools. People often think of physics in the same weight as other STEM subjects like chemistry and biology, but they do not realize how important and unique its role is in improving STEM specializations, particularly in Tanzania.

1.4 Objective

To raise awareness and evidently convince secondary school education administrators and policymakers that education objectives need refine and adjustment to better prepare students for STEM careers, ensuring they are equipped to meet the demands of the 21st-century workforce.

1.4.1 Specific objectives

- i To increase awareness of the disparity between the potential required job placement and existing educational practices in STEM within cities, thereby informing educators of the necessary educational requirements.
- ii To clearly demonstrate the conditions needed to sustain STEM education in a typical urban city in Tanzania.
- iii To analyze gender inequality in STEM education between public and private schools and identify opportunities available in private schools.

2 Literature review

The link between mathematics, physics, and retention in STEM fields has been extensively researched (Berkowitz et al., 2022). Studies indicate that physics and mathematics are fundamental components for numerous STEM professions, owing to their analytical precision, emphasis on problem-solving, and relevance to practical scientific and

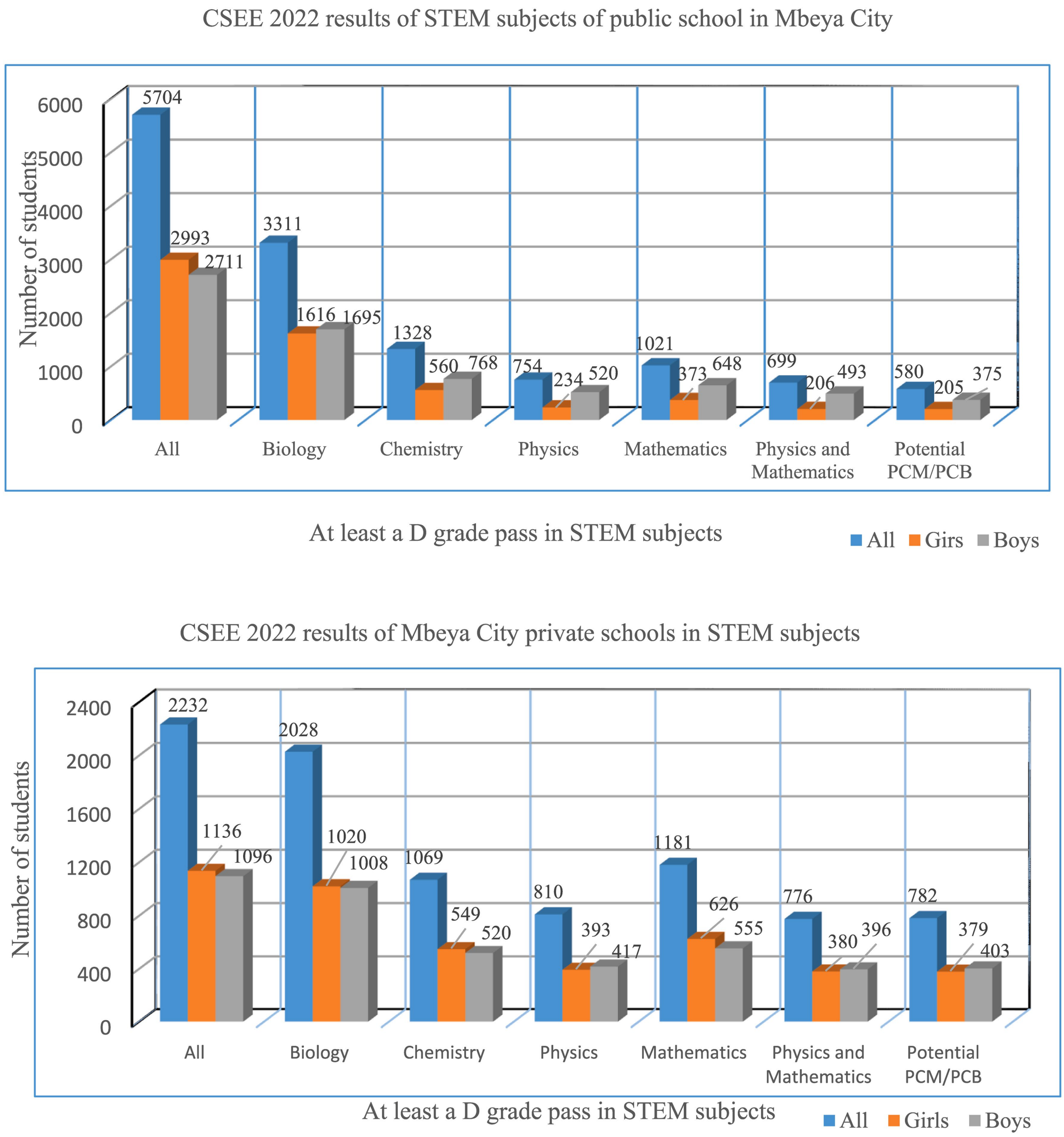

FIGURE 3
CSEE 2022 performance in STEM subjects. Source: Extracted from NECTA (CSEE 2022).

technical challenges (Bottia et al., 2015). The role of mathematics and physics for secondary school science students is vital for promoting sustainability in 21st-century STEM fields. Integrating these subjects with sustainability education can provide students with the essential skills and knowledge needed to tackle global challenges (Smith and Watson, 2016). This synthesis emphasizes the importance of focusing on the technical aspects of mathematics and physics education, as it not only improves performance in STEM but also promotes sustainability in STEM education.

Building on this cognitive foundation, the higher-order thinking abilities necessary for success in STEM fields are developed in tandem with mathematics and physics (Gradini et al., 2025). While physics converts these abstractions into practical applications, allowing students to comprehend and model physical processes, mathematics enhances students' ability to reason abstractly (Psycharis, 2013). The analysis by Kokkelenberg and Sinha (2010) underscores that advanced mathematics preparation, enrolments in Advanced Placement (AP) courses, high school GPA, and college experiences are significant determinants of pursuing and succeeding in STEM areas, as well as enhancing retention rates. All of these results show that having a solid foundation in physics and mathematics not only improves conceptual knowledge but also helps with retention and success in the STEM pipeline (Carver et al., 2017).

Related to this, mathematical literacy plays a diverse array of STEM professions, including engineering, computer science, and data analysis, necessitating a robust understanding of mathematical principles for success and advancement in these domains (Mayorova et al., 2021). High proficiency in mathematics correlates with higher academic performance in STEM courses, leading to better career prospects (Tikly et al., 2018). This indicates that early proficiency in mathematics bolsters students' confidence and readiness for advanced STEM education, thus enhancing retention rates.

Furthermore, physics serves as a fundamental entrance to other STEM professions, including engineering and technology, by fostering essential spatial reasoning and problem-solving abilities required for these disciplines (Miller and Halpern, 2013). Physics provides a deep understanding of natural laws, and its experimental nature appeals to students interested in innovation and discovery (Kane and Gelman, 2020). Studies indicate that students with a robust grounding in physics are more likely to pursue professions in STEM fields, especially in aerospace, mechanical engineering, and computer science (Black et al., 2021).

2.1 Challenges and interventions

Notwithstanding the advantages, numerous students encounter challenges in mathematics and physics owing to perceived difficulty or inadequate engagement (Badmus and Jita, 2024). Interventions such as enhanced pedagogical techniques, practical applications, and the encouragement of inquiry-based learning have demonstrated efficacy in enhancing student engagement and retention in these disciplines, resulting in heightened interest in STEM vocations (Savelsbergh et al., 2016).

2.2 Gender disparities

Research underscores disparities in performance across genders in mathematics and physics, affecting retention in STEM professions (Huang et al., 2020). Initiatives aimed at closing these gaps, such as mentorship programs, targeted support, and inclusive teaching strategies, have been effective in increasing female participation in STEM fields (Nweje et al., 2025). However, a systematic review by Verdugo-Castro et al. (2022) concluded that gender stereotypes significantly contribute to the gender gap in STEM. To close this gap, it's essential to focus on mentorship and the influence of family, school environment, peer pressure, and broader cultural factors (Cvencek et al., 2020; Verdugo-Castro et al., 2022).

Collectively, the literature demonstrates that strong preparation in mathematics and physics is a decisive factor influencing students' entry into and persistence within STEM pathways (Mansour et al., 2024; Xu and Hsu, 2024). High achievement in these subjects not only predicts long-term retention but also shapes students' confidence, interest, and career aspirations, reinforcing their relevance as foundational disciplines within the STEM pipeline (Xu and Hsu, 2024). At the same time, persistent challenges, including gender disparities, negative stereotypes, and insufficient engagement, continue to hinder equitable participation, particularly among girls (Dasgupta and Stout, 2014). Addressing these barriers through targeted mentorship, inclusive classroom practices, and supportive school and cultural environments has proven effective in broadening participation (Thomas, 2016). While other STEM subjects, such as chemistry and biology, also contribute to student retention, the unique conceptual and analytical roles of mathematics and physics give them unmatched influence in preparing learners for advanced STEM study (Cho and Cho, 2024). Furthermore, interdisciplinary approaches such as using mathematical physics modelling enhance conceptual connections and promote practical, problem-based learning, thereby making STEM education more meaningful and sustainable (Dominguez et al., 2024). Together, these insights underscore that strengthening mathematics and physics education, while simultaneously addressing gender and engagement barriers, is central to sustaining a robust and diverse STEM pipeline (Nweje et al., 2025).

This study is anticipated to provide more evidence of the role of earlier and persistent engagement in mathematics and physics for learners. This, in turn, strengthens grounds in physics for the young learner, which boosts performance in all STEM subjects.

3 Methods

3.1 Pure quantitative methods (census-based) design

This study adopts a quantitative research design based on secondary analysis of the 2022 Certificate of Secondary Education Examination (CSEE) results obtained from NECTA. The dataset includes the full population of public and private secondary schools in Mbeya City. Schools were categorized by ownership and analyzed to compare patterns of STEM enrolment and performance across biology, chemistry, mathematics, and physics, with particular attention to gender disparities. Descriptive statistics, frequency tables, bar charts, and comparative graphs were used to summarize performance differences. Chi-square tests were conducted to examine associations between school type, gender, and subject outcomes. All analyses were performed using ethically obtained secondary data in compliance with NECTA data-access guidelines.

3.1.1 Data collection

The researcher received Mbeya City's 2022 CSEE data from NECTA (NECTA, 2022). Mbeya City was purposely chosen because it is one of Tanzania's five major cities, having a higher concentration of private secondary schools than rural districts and other regions (Mulungu, 2018). This framework enables relevant comparisons between public and private schools, particularly regarding STEM enrolment and performance. The researcher believes that private schools can help promote gender balance and improve STEM subject scores. By examining all public and private schools in the city, the study gives a comprehensive view of city school dynamics in Tanzania, where policy considerations for boosting the STEM pipeline are especially important.

3.2 Data analysis

3.2.1 STEM subjects' performance analysis

The schools were arranged in increasing order of total number of candidates for the CSEE, with line graphs for easy comparison and convenience. In all 58 schools, the performance in STEM subjects indicated that fewer pupils selected physics compared to chemistry. Furthermore, the graphs for biology, chemistry, and physics exhibited a clear demarcation (without overlap), with physics consistently demonstrating the lowest performance levels (Figure 4) across all institutions. Overlaps were observed when plotting STEM topics against basic mathematics, especially between basic mathematics and chemistry or basic mathematics and physics (Figure 5), with infrequent overlaps between basic mathematics and biology. The graphs in Figures 4, 5 ascend along the positive horizontal axis, indicating the sequence of schools by increasing student population.

3.2.2 Gender equity analysis

The chi-square approach was employed to ascertain if a substantial gender disparity existed in the pass rates of STEM disciplines. Chi-square was considered best choice following the fact that data are categorical, i.e., girl or boy, pass or fail, moreover the study dealt with counts and not continuous data. Not only that but also, our assessment was not about prediction which would necessity logistic regression. Thus, the degrees of freedom were computed, and a critical value (p) was derived from statistical tables. The test statistic was calculated independently for public and private schools. Decisions were predicated on a 95% confidence interval. The quantity of passes in STEM disciplines was documented in Tables 1, 2.

Calculation of Chi-square, (χ^2).

The number of candidates in parentheses of Table 1 are theoretical expectations and the rest was the observation. Five steps guided to justify whether gender has an effect in the performance of STEM subjects.

Step 1: Define Null (H_0) and Alternative Hypotheses (H_1):

H_0: In Mbeya city, students from private secondary schools do not exhibit gender-based disparities in completing STEM subjects. Thus, both boys and girls are expected to perform at similar levels in these subjects.

H_1: For students in private secondary schools in Mbeya city, gender influences the likelihood of passing STEM subjects, in particular, boys perform better than girls.

Step 2: State the confidence interval: $\alpha = 0.05$

Step 3: Calculate the degree of freedom (df) and state the critical value (p): $df = (rows - 1)(columns - 1) = (2-1)(4-1) = 3;$ so, the critical value, $p = 7.81$.

That is, if chi-square (χ^2) is greater than 7.81, reject H_0.

Step 4: Calculation of test statistic $\chi^2 = \Sigma \frac{(f_o - f_e)^2}{f_e}$ where where $f_e = \frac{f_c f_r}{n}$ and $f_0 = observed\ frequency, f_e = expected\ frequency,$ $f_c = frequence\ of\ the\ column,\ f_r = frequence\ of\ the\ row, n = total\ number\ of\ subjects.$

Step 5: Calculation of theoretical pass expectations: Girls expected to pass biology in the first cell of, $(Girls, biology)_{11} = \frac{(2028 * 1153)}{2255}$

$$\chi^2_{pr} = \Sigma \frac{(f_o - f_e)^2}{f_e}$$

$$\chi^2_{pr} = \frac{(1020-1037)^2}{1037} + \frac{(1008-991)^2}{991} + \frac{(549-547)^2}{547} + \frac{(520-522)^2}{522} + \frac{(393-414)^2}{414} + \frac{(417-396)^2}{396} + \frac{(626-604)^2}{604} + \frac{(555-577)^2}{577} = 4.40429$$

$\chi^2_{pr} = 4.40 < 7.81 = p$. Therefore, the null hypothesis is true.

The author applied a similar test to candidates from public schools.

Similarly, $\chi^2_p = \Sigma \frac{(f_o - f_e)^2}{f_e} = 318$ for Table 2; however, $\chi^2_p = 318 > 7.81 = p$.

Therefore, the null hypothesis is rejected.

3.2.3 Analysis of STEM studies prospects

The investigation went further to ascertain students with a pass of at least a D grade in both physics and basic mathematics, but also students with at least 2 Cs and one D pass in PCB or PCM combination. We classified the latter as potential PCB or PCM candidates. Students having passed in both physics and basic mathematics or potential to pursue either PCB or PCM are considered eligible to further careers in STEM specializations.

In this regard, 783 (35%) were prospective STEM careers of the 2,255 candidates from private schools, of which 308 were girls (Table 3). On the other hand, out of 5,704 candidates from public schools, 699 (12.25%) candidates, of which 206 were girls, could advance in STEM career opportunities (Table 4).

4 Results

Besides analysis of acute STEM enrolment and performance in secondary schools that impacts negatively the future of STEM careers especially in public schools, gender issues were analyzed in both public and private schools using the Chi-square statistical tool. Nevertheless, gender disparity was evident in public schools. Thus, the calculated critical value, p = 7.81, and the test statistic, $\chi^2_{pr} = 4.40$ for all students' performance in STEM subjects for private schools and $\chi^2_p = 318$ for public schools. It is clear that $\chi^2_{pr} = 4.40 < 7.81 = p$, and $\chi^2_p = 318 > p$. In this context, we accept the null hypothesis for private schools, while rejecting it for public schools. This suggests that private schools in Mbeya city of Tanzania promote gender equity in the performance of STEM subjects, ensuring that both girls and boys perform on an equal footing. In contrast, public schools display a clear gender disparity in STEM subjects' performance.

Additionally, it is evident (Figure 3) that success in both physics and mathematics plays a crucial role in determining the number of STEM career prospects in secondary schools. The number of students' achievements in both physics and mathematics matches with potential PCB and PCM combinations for A level prospects. This might sound obvious because a student in PCB or PCM needs a common subject physics to qualify. However, the strong point here was that all science students regardless of being ready for PCB or PCM should sit for physics in their CSEE for sustainability in STEM. That will increase performance, first of all in mathematics, since physics students will need mathematics. Secondly, PCM and PCB takers shall be enhanced, and lastly, sustainability in other combinations related to STEM will be improved.

5 Discussion

The role of physics to science students is well demonstrated in Figures 4, 5, which illustrates plots of performance in physics,

TABLE 1 Overall CSEE 2022 results of STEM subjects in private schools.

Gender	The number of students who passed in the STEM subjects of				
	Biology	Chemistry	Physics	Mathematics	Total
Girls	1,020 (1037)	549 (547)	393 (414)	626 (604)	1,153
Boys	1,008 (991)	520 (522)	417 (396)	555 (577)	1,102
Total	2028	1,069	810	1,181	2,255

Source: Prepared by the author.

TABLE 2 CSEE students' performance in 26 public schools in STEM subjects.

Gender	Number of students who passed in STEM subjects				
	Biology	Chemistry	Physics	Mathematics	Total
Girls	1,616 (1737)	560 (697)	234 (396)	373 (536)	2,993
Boys	1,695 (1574)	768 (631)	520 (358)	648 (485)	2,711
Total	3,311	1,328	754	1,021	5,704

Source: Prepared by the author.

TABLE 3 Estimated CSEE 2022 candidates to enter STEM careers from private schools.

Gender	Pass in physics and math	Potential PCB or PCM	Potential STEM candidates	Total
Girls	380	379	380	1,153
Boys	396	403	403	1,102
Total	776	782	783	2,255

Source: Prepared by the author.

chemistry and biology. The plots of physics are at the lowest suggesting that performance was the lowest of all, followed by chemistry and students did the best of all STEM subject in biology. The reason is that chemistry is more like physics than biology; alternatively, chemistry is more dependent on physics than biology. Thus, the fewer students in physics, the fewer students in chemistry, at least compared to students in biology. In order to boost students in chemistry and biology, performance in physics is fundamental both in number of students and grades. On the other hand, physics needs to go with mathematics for science students, which has been ignored by treating physics as less important than chemistry or biology in the Tanzanian curricula (John, 2024). This study suggests that physics and mathematics need special attention if one needs to enhance STEM education in their Nation (Galili, 2018). Alternatively, solving mathematics issues is not enough for enhancing performance in physics, they need to be dealt together. Galili (2018) highlighted that some evolution of mathematics through physics is indispensable, suggesting that mathematics and physics are interwoven.

Although mathematics is often regarded as the foundational subject for science students (Nakai, 2022), the findings of this study refine this view by indicating that, when supported by strong mathematical competency, physics is a more foundational and integrative role in science than mathematics in scientific learning (Rossdy et al., 2019).

Performance in STEM subjects plays a critical role in the selection of high school PCB or PCM combinations, which ultimately determines prospects to pursue STEM career opportunities in higher education institutions. Among the 2,232 candidates from private schools, at least one-third were identified as having potential for STEM studies, with almost half of them being girls. Conversely, public schools, with 5,704 candidates, contributed around 10% students had the potential to join STEM fields in which less than 4% were girls. It is noteworthy that this percentage represented about 7% of all girls. Comparably, fewer than 20% of the boys had the potential to advance into STEM careers. This highlights the gender differences in STEM career opportunities and underscores the importance of more support for female students in public schools to increase their participation in STEM fields.

Although Mbeya city has made a milestone in the long-awaited achievement for girls to surpass boys' enrolment in secondary schools (Figure 1), both in public and private schools (Sanga, 2016). The challenge remains to sustain these students in quality education in accordance with the United Nations' fourth Sustainable Development Goal (SDG4). From the literature, there are still setbacks for girls, such as early pregnancy and cultural issues that hinder girls' progress in schools, possibly in public schools (Mwalongo and Mwalongo, 2018). While the performance of girls in STEM subjects in private schools was free of gender disparity, in contrast, regardless of more girls in the overall total graduates, the number of girls passing in every STEM subject is lower than the comparable number of boys in public schools, as shown in Figure 3.

5.1 What is in the literature about physics curricula?

Mathematics is the art/science of quantification, and being strong in this art/science, it is convenient to model physics concepts into

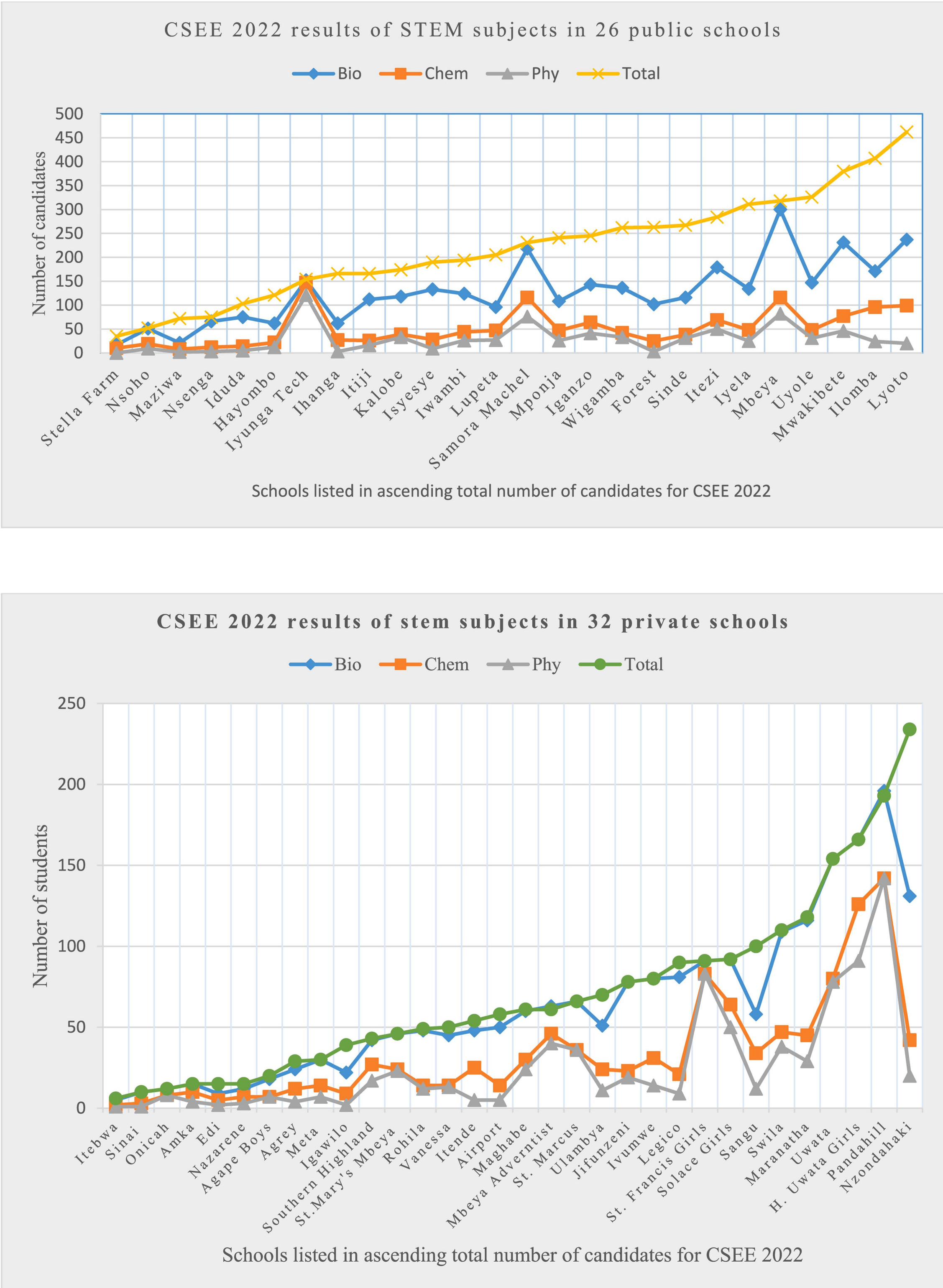

FIGURE 4
Plots of the number of students who passed physics, chemistry, and biology in every school. Source: Extracted from NECTA (CSEE 2022).

mathematical language (Wilson, 2014). However, contextualizing physics concepts have nothing to do with mathematics; that is, physics stands alone in this view (Greca and Moreira, 2002). On the other hand, if one cannot contextualize the physics concept, then regardless of one's background in mathematics, one has nothing to contribute to physics (Ingerman and Booth, 2003). Thus, the physics concept stands alone (Gautreau and Novemsky, 1997). Nonetheless, physics loves mathematics, but they never substitute one another (Wilson, 2014).

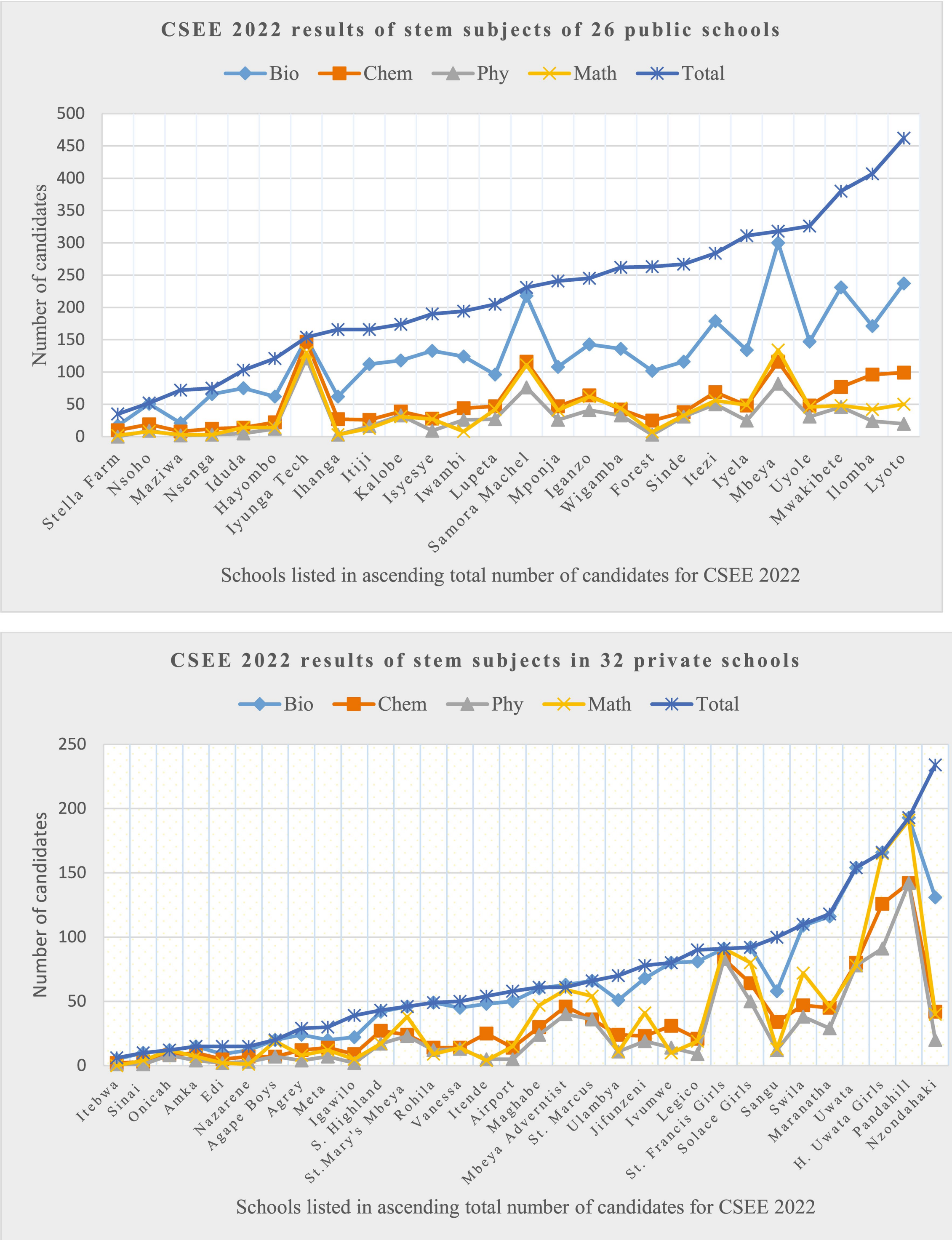

FIGURE 5
Plots of the number of students who passed physics, chemistry, biology, or mathematics in every school. Source: Extracted from NECTA (CSEE 2022).

Most of the curricula in secondary schools are trying to match mathematics to physics or a similar subject (Gingras, 2001; Pospiech et al., 2015), which is not proper (Figure 5), and due to that, physics and mathematics have suffered several setbacks, particularly in elementary schools in Nigeria, the UK, the US, and more (Barmby and Defty, 2006; Erinosho, 2013; Ornek et al., 2008).

5.2 Curriculum, classroom practice, and policy implications

The interpretation of this study's findings relies primarily on existing literature, as qualitative data were not collected. The results (Figure 3) suggest the need to enhance inclusive STEM pedagogy at

TABLE 4 Estimated CSEE 2022 candidates to enter STEM careers from public schools.

Gender	Pass in physics and math	Potential PCB or PCM	Potential STEM candidates	Total
Girls	206	205	206	2,993
Boys	493	375	493	2,711
Total	699	580	699	5,704

Source: Prepared by the author.

the secondary school level. Strengthening early instruction in mathematics and physics is essential for improving students' readiness for advanced STEM learning (Counsell et al., 2016; Verawati and Nisrina, 2025). This study proposes that the national curriculum should require all science students to sit for physics and mathematics in the CSEE to broaden participation in STEM pathways. Such a reform has the potential to improve gender equity by ensuring equal exposure to core STEM subjects (Wade and Zaringhalam, 2019). Implementing this proposal would necessitate adjustments to the existing curriculum. Furthermore, corresponding revisions to education policy may be required to support sustainable long-term STEM development.

5.3 Limitations of the study design

Because the study uses cross-sectional secondary CSEE data, the findings are correlational and do not establish causal relationships between school type and STEM outcomes. The analysis is limited to variables available in the NECTA dataset, meaning factors such as teacher quality, school resources, and student background could not be examined directly. Additionally, the study focuses on one city, which may limit generalizability to other cities.

5.4 Future research

To understand the gender and performance trends seen in this quantitative study, future research should use qualitative methods like observations and interviews. It would be easier to account for elements not included in the NECTA dataset if additional school variables were included, such as teacher qualifications, laboratory resources, and socioeconomic setting. Longitudinal research employing several years' worth of CSEE data may show patterns in STEM achievement and involvement over time. Generalizability would be improved by extending the analysis to rural and semi-urban areas. More research utilizing data from individual students may be able to pinpoint more accurate predictors of STEM persistence. Research assessing particular STEM initiatives, like resource enhancements or mentoring, would also offer useful policy insights. Understanding of STEM sustainability may also be strengthened by regional comparisons with other nations.

5.5 Recommendation

Strengthening mathematics and physics instruction should remain a key priority for education policymakers. It is also important to require all science students preparing for the CSEE to sit for physics examinations. This can be supported through improved funding for laboratory facilities, essential learning materials, and continuous professional development for STEM teachers. To address gender disparities in STEM pass rates, gender-responsive strategies such as mentorship, role-model engagement, and targeted academic support for girls should be introduced (Wang et al., 2023). Stakeholders may also adopt policies that reduce class sizes or provide additional support systems in overcrowded public schools. Better alignment between school resources and STEM curriculum requirements can help narrow performance gaps. Finally, stronger partnerships between government, schools, and industry can enhance real-world STEM exposure and sustain interest in STEM careers (Hobbs and Kelly, 2020).

6 Conclusion

This study involved public and private schools totaling up to 58, with about 7,900 students in Mbeya city, of whom about 50% were in private schools, representing one-third of the total students. In the first place, NECTA processed the results in divisions based on the general performance of students who sat the 2022 CSEE. This study extended observations to STEM subjects' performance. An estimation of more than two-thirds of students in private schools scored divisions I and II, whereas in the same divisions, less than 20% of students passed from public schools.

Accordingly, more students in private schools had the potential to pursue a career in STEM studies. Specifically, the study revealed that in private schools, about one third of each group (girls or boys) had the potential to further their career in STEM studies. On the other hand, the number of boys were more than twice number of girls with the potential to advance in STEM studies from public schools. According to this study, less than one-fifth (20%) of all graduates could advance to STEM fields.

The study also revealed that performance in both mathematics and physics was the determinant of students to proceed and sustain in STEM studies. Thus, it was recommended to emphasize that students take both physics and mathematics for all STEM prospects. In so doing, it shall boost students' retention in STEM based on the fact that physics concepts span other STEM subjects, whereas mathematics enhances the study of physics. Furthermore, educational policy makers need to review educational policies by setting favorable environment for private sectors investment to take advantage of private sectors for more student enrolment in STEM studies. That shall upscale girls' both enrolment and performance in STEM studies. Collaboration of public schools with private school investors is indispensable, so as to share experience on how to address gender issues and STEM participation of the students. In brief, it has been realized that private schools do not only outperform public schools in the division wise performance but also demonstrated capacity to leverage girls in STEM performance to the extent of freeing from gender issues not only in the enrolment but also in the performance.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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

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