Gender Disparities in STEM Education: A Statistical Decomposition of PISA 2022 Scores

Hashim Khan[1], Shafa Ayaz[2], Summayya Batool[3]

[1] Ajou University, South Korea, Graduate School of International Studies,
   Email: hashim@ajou.ac.kr
[2] University of Strathclyde, Glasgow UK, Teacher Training & Education,
   Email: sabz.ayaz@gmail.com
[3] Department of Chemistry, Quaid-i-azam University Islamabad Pakistan,
   Email: summayya.batool@chem.qau.edu.pk

Abstract

Worldwide, researchers are studying the differences in how genders perform in science and mathematics. In a complicated educational system like Pakistan's, evaluating differences in isolation would not lead to a complete understanding. Therefore, this study evaluates changes in performance patterns in Science and Mathematics, looking at both genders and comparing public and private institutions. Data was collected from a large group of primary school kids throughout the country (n=15,391) utilizing SATs/MATS. Data analysis using independent t-tests and two-way ANOVA. Results revealed that girls outperformed boys in Science ($p<0.01$) while no gender differences in performance were observed in Mathematics. The relationship between gender and school systems had a substantial impact, but only in mathematics. Specifically, females performed better in public schools, but this difference lessened in private schools. The findings suggest that gender-fair policies and practices should be considered in science and mathematics education.

Keywords: Gender Disparity, Gender-Based Performance, Science and Mathematics Achievement, Gender Difference Across School Systems, Large-Scale Study.

Introduction

Gender differences in education, including access, achievement, and learning, are a complex and complicated subject, and they continue to be a major area of study and policy work worldwide. The possible effects of gender inequality on a society's economic and social growth have been widely debated (Global Education Monitoring, 2020). Recognizing the existing situation, numerous reforms and efforts have been undertaken to address gender inequality in education at all levels. Encouragingly, the difference in enrollment numbers across genders has decreased over the last twenty years. For example, the number of females enrolled in elementary and secondary schools grew by 55% during the previous twenty-five years (Global Education Monitoring, 2020). However, the data on the gender disparity in student performance, notably in Science and Mathematics, is still unclear. Recent worldwide data shows that certain nations have improved females' performance in Science and Mathematics (TIMSS, 2019; GEM, 2020). In contrast, a gender gap still remains in many countries, notably in Lower-and-Middle Income Countries (LMICs), with a noticeable advantage for males (Global Education Monitoring, 2022; TIMSS, 2019). A major reason for the differences in academic performance between genders might be the impact of stereotypes. These stereotypes can affect students' attitudes towards school and, as a result, their academic success

and future careers in Science and Mathematics (Brown & Alexandersen, 2020; Lindberg et al., 2010; Wrigley-Asante et al., 2023). Moreover, gender stereotypes also shape ideas, choices, and attitudes about learning in Mathematics and Science. Several unique contextual factors directly and indirectly impact the difference in performance between genders. In many countries, including Pakistan, the school system is a key determinant in both school choice and student achievement (Aslam, 2009; Kingdon, 2020; Nguyen & Raju, 2014). Specifically, large-scale assessments in Pakistan reveal that kids in private schools do better than those in public schools (Bhutta & Rizvi, 2022). Aslam's (2009) research showed that private education explains 19% of the differences in how well pupils do in math. However, Pasha (2023) revealed that females are less likely to attend private schools. However, when it comes to performance Studies in Pakistan have shown that, when considering gender, females often score better in Science, while boys prefer to excel in Mathematics (Fussy et al., 2023; Shah et al., 2020). This raises important issues about disparities in performance based on gender. For example, do the inequalities we see depend on the students' gender? Or, then, are the inherent qualities of private schools the reason for the differences in performance, with males benefiting more since they are more likely to attend private institutions? This study aims to answer these issues by comparing how different genders perform in science and mathematics throughout the nation. It then compares public and private schools to create a complete picture. Using data from a nationwide dataset, this research adds to the current knowledge base in two main ways. This study offers a more thorough understanding of the growing inequalities in how male and female students perform in Science and Mathematics in Pakistan. Following this, the study investigates the distinctions between public and private educational systems, which are the two primary and different types of education providers. This study adds to worldwide efforts to achieve gender equality in education, as outlined in the Sustainable Development Goals, notably SDGs 4 and 5. It does this by examining the changing patterns within the specific context of Pakistan. This topic is relevant to both local and international groups seeking to achieve gender equality in education.

Research Question
This paper responds to the following research questions:
1. Is there any significant difference in the performance of boys and girls in Science and Mathematics in elementary grades across Pakistan?
2. Are there any separate and interactive effects of student gender and school system, on their performance in science and mathematics?
3. Review of Relevant Literature

Trends of Students' Performance in Science and Mathematics
Differences in how genders perform in science and mathematics have been investigated in several places throughout the globe. The most important research has explored disparities in isolation, by evaluating how girls and boys perform differently on standardized achievement exams (TIMSS, 2019). This kind of evidence has a long history and a vast breadth, having been collected globally since the 20th century. Historically, science and mathematics were considered fields for men, and boys showed a strong, stereotypical interest in these subjects (Hyde et al., 1990; Starr & Simpkins, 2021). This, in turn, led to better performance by boys (Else-Quest et al., 2010; Makarova et al., 2019; Xie et al., 2023). However, these tendencies have shown continual shifts throughout time and in different circumstances. The existing research offers no clear conclusion (Baye & Monseur, 2016; Borgonovi & Han, 2021; Meinck & Brese, 2019; TIMSS, 2019). Sometimes, studies show no differences in academic achievement (Ajai & Imoko, 2015; Bessudnov & Makarov, 2015; Erturan & Jansen, 2015; Sarouphim & Chartouny, 2016; Tsui, 2007). Other studies suggest girls do better in Science and/or Mathematics (Arora et al., 2012; Global Education

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Monitoring, 2022; Gonzales et al., 2008; Mullis et al., 2004; Saeed et al., 2005; Shah et al., 2020), or that boys perform better in these subjects (Asante, 2010; Edgerton et al., 2012; Kumar & Choudhury, 2022; Lau & Lam, 2017; Reilly et al., 2015; Reilly et al., 2019).   Researchers have used meta-analysis to combine previous studies, aiming to provide a complete knowledge of how genders vary. For example, Lindberg and his team (2010) did a meta-analysis of over 242 research published over eighteen years, from 1990 to 2007. They showed that girls and boys performed similarly in Science and Mathematics.   In contrast, a meta-analysis by Ouma and Nam (2015), concentrating on underdeveloped areas, particularly in Africa, showed that males did better in Mathematics.   However, these findings are also equivocal, which highlights the need for further specialized research on how gender affects performance.

Schools Systems and Gender Differences
It's stated that investigating gender disparities without considering other related issues could not lead to reliable findings. Several variables, whether directly or indirectly, may affect the observed variations in performance between genders in Science and Mathematics.   For example, gendered views about science and mathematics, which often see mathematics as a male-dominated field (Butt & Dogar, 2014; Nosek et al., 2009), influence how parents, teachers, and students view and approach these subjects. This, in turn, affects how well students do (Kane & Mertz, 2012; Leder, 2019).   Moreover, gender stereotypes can impact the educational choices of both boys and girls. Aslam and Kingdon (2008) found that parental choices on schools, whether public or private, and how much they spend on their children's education, often favor boys.   As a result of this home prejudice, parents tend to spend more in their sons than in their daughters. Studies by Aslam (2009) and Pasha (2023) show that females are much less likely to be enrolled in private schools. Moreover, comparable results of prejudice within families have been seen in India (Kumar & Choudhury, 2022).   This raises the question of whether the differences in performance are related to the pupils' gender or the specific educational system they are in.   The next section will analyze the existing research on how school systems affect performance, which requires a comprehensive analysis of how these two separate factors interact. Many studies have examined how school-related characteristics, including whether a school is public or private, affect kids' academic success (Ahmed et al., 2013; Akhter, 2017; Beese & Liang, 2010; Mohammadpour & Shekarchizadeh, 2015; Thappa, 2015).   It's often assumed that children at urban or private schools do better in Science and Mathematics.   This notion is based on the idea that urban schools have benefits, such as better infrastructure and greater resources, compared to schools in rural regions (Organisation for Economic Co-operation and Development, 2019).   Moreover, parents' perspectives on private and public schools are comparable, regardless of where the schools are located.   Parents often choose private schools over public ones because they believe private schools provide better professors and more effective teaching methods. They also appreciate the help provided for external exams and the security measures in place to protect their children (Andrabi et al., 2008; Ahmed et al., 2013; Akhter, 2017).   On the other hand, public schools are failing to satisfy the established requirements for excellent education (Bhutta & Rizvi, 2022). Several factors contribute to the problems in public school quality, including insufficient basic facilities and a lack of responsibility for instructors (Awan & Zia, 2015; Andrabi et al., 2008; Beese & Liang, 2010).   Therefore, parents with the financial means to pay for private education are more likely to enroll their children, especially sons, in private schools, a trend seen in Pakistan (Andrabi et al., 2008; Pasha, 2023). Furthermore, a consistent finding throughout the research indicated that kids attending private schools in Pakistan demonstrated superior performance in fundamental academic disciplines, including Science and Mathematics (ASER, 2020; Awan & Zia, 2015; Beese &). Liang (2010) and Thappa (2015) have both contributed to this area of study.   Similar patterns have been reported in other nations (Malacova, 2007; Nath, 2012; Ndaji et al., 2016; Singh, 2014;

Smith-Wooley et al., 2018; Thappa, 2015; Zuilkowski, 2018).   The issue that emerges is why private schools often do better than public institutions.   Public school instructors are usually expected to have specified academic and professional qualifications to be employed. at contrast, the qualifications for teachers at private schools are sometimes not as strictly defined (Akhter, 2017; Singh, 2014).

Context of the study
Pakistan's geography is a patchwork of six distinct regions: Punjab, Sindh, Khyber Pakhtunkhwa, Balochistan, Azad Jammu Kashmir, and Gilgit Baltistan.   The educational system includes basic education, covering grades one through eight; secondary education, covering grades nine through twelve; and university education, which offers undergraduate, graduate, and postgraduate programs.   Pakistan's education system is largely divided into two parts: public schools, which the government manages, and private schools, which are run by private organizations.   In the 2017-18 academic year, Pakistani public schools enrolled 56% of pupils, with boys making up 55% and girls 45%. The remaining 44% of students attended private schools, including 56% boys and 44% girls.   Moreover, variations exist between public and private schools in terms of the language used for teaching, how exams are given, and the textbooks used (AEPAM, 2018). Despite these distinctions, science and mathematics instruction has remained a core element of formal education in both systems.   The importance of mathematics and science in solving real-world issues might be a reason for this.   Mathematics helps us understand the basic patterns and relationships in things, and it also helps us think abstractly. Science, on the other hand, allows us to fully understand the qualities and connections of objects and events in the world (Beswick & Fraser, 2019; National Research Council, 2012).   In the 21st century, the significance of these fields is growing, both worldwide and locally, and they are still relevant in schools today (Nakakoji & Wilson, 2020).   In Pakistan, the school curriculum requires children to study Science and Mathematics from early childhood education (ECCE) through elementary school, specifically till Grade VIII.   Therefore, science and mathematics education in schools is provided to both boys and girls, offering the same opportunities to all pupils, regardless of their background.

Methodology
This study is based on research performed in primary schools throughout Pakistan (Bhutta & Rizvi, 2022).   This research employed a cross-sectional survey approach.   The data came from 15,343 students in grades 5, 6, and 8. These students were chosen from 153 randomly selected schools, which included 78 governments and 75 private institutions. These schools were located in 25 districts, representing all six regions of Pakistan: Punjab, Sindh, Khyber Pakhtunkhwa, Balochistan, Gilgit Baltistan, and Azad Jammu & Kashmir. This study focused on evaluating student performance, using valid and reliable Mathematics Achievement Tests (MATs) and Science Achievement Tests (SATs) for each grade level (Bhutta & Rizvi, 2022).   To test the internal consistency of the instruments, Cronbach's Alpha was calculated for both SATs and MATs. The results showed a good range (0.60 to 0.78) for both SATs and MATs across all grades. The distribution of content across subject areas in the SATs (Biology, Physics, Chemistry, and Earth Sciences) and MATs (Number & Operations, Geometry & Measurement, Algebra, and Information Handling), as well as the cognitive levels assessed (knowledge, application, and reasoning), was consistent with the National Curriculum 2006.   The assessment contained both Multiple Choice Questions (MCQs) and Constructed Response Questions (CRQs).   All the MATs and SATs contained thirty questions, except for the fifth-grade test, which had twenty questions. In addition, demographic questions were used to obtain information about the pupils' characteristics, such as their gender and school system.   To reduce the impact of classmates, students took the tests in a controlled environment. They completed each test within a 50 to 60-

minute time frame, and the researcher was present throughout the whole process. The data collection happened between October 2018 and January 2020. The data analysis process involves many phases. After confirming that the raters agreed, the CRQs were scored using a pre-existing rubric. The multiple-choice questions were graded using SPSS. The study utilized the average percentage scores. After confirming the essential assumptions of parametric testing, including normality and equal variances, an independent t-test was used to assess the differences. Furthermore, the extent of the changes was evaluated by calculating the effect size (r). Effect size benchmarks were identified as small (r = 0.1), medium (r = 0.3), and large (r = 0.5) (Field, 2017). Finally, a two-way ANOVA was performed to check whether there was an interaction between the two independent variables: gender and school system. The dependent variable in this study is defined as the students' results on the SAT and MAT exams.

Results Analysis
Demographic Characteristics of the Sample
Of the total 15,391 students recruited for the study, the gender-wise distribution revealed almost equal representation with a slight greater participation of boys (n=7968; 52%) than girls (n=7423; 48%). The variance in gender ratio is the manifestation of the enrolment rate of boys which is greater than girls in the country (UNESCO, 2021; NEMIS, 2019). Furthermore, school system-based distribution of the sample shows that relatively a larger number of students from public schools (n=9270; 60%) participated in this study than students from the private schools (n=6121; 40%). This pattern was consistent for gender-based comparison in both, public and private sector schools. For instance, there were more girls in public schools (n= 4777; 31%) than private schools (n= 2627; 17%), and the same trend for boys was observed as well. The less participation of girls from private schools validates the findings of Aslam (2009) and Pasha (2023), who reported that parents gave less chances to their female children to be enrolled in private schools.

RQ 1: Is there any significant difference in students' performance between girls and boys?
The results of an independent t-test, presented in table 1, revealed that girls have significantly outperformed boys' in science (p<0.001), while there was no significant difference in mathematics achievement.

Table 1: Comparison of Students' Performance in Science and Mathematics by Gender

Subject	Gender	N	Mean (SD)	t	p	Effect size
Mathematics	Boys	7939	26.90 (15.78)	-1.378	0.169	n.s
	Girls	7404	27.21 (14.83)			
Science	Boys	7893	33.21 (16.63)	-7.179	0.001	r=0.06
	Girls	7394	35.10 (15.47)			

These results suggest that girls have shown a better understanding of scientific concepts, while both girls and boys have demonstrated similar performance in Mathematics. Interestingly, girls have an edge over boys in Mathematics; however, the difference is not statistically significant (p> 0.05). Notably, regardless of gender, students have performed better in science as compared to Mathematics.

RQ2: Are there any separate and interactive effects of student gender and school system, on their performance in science and mathematics?
The results of two-way ANOVA as given in table 2 help to understand the separate and
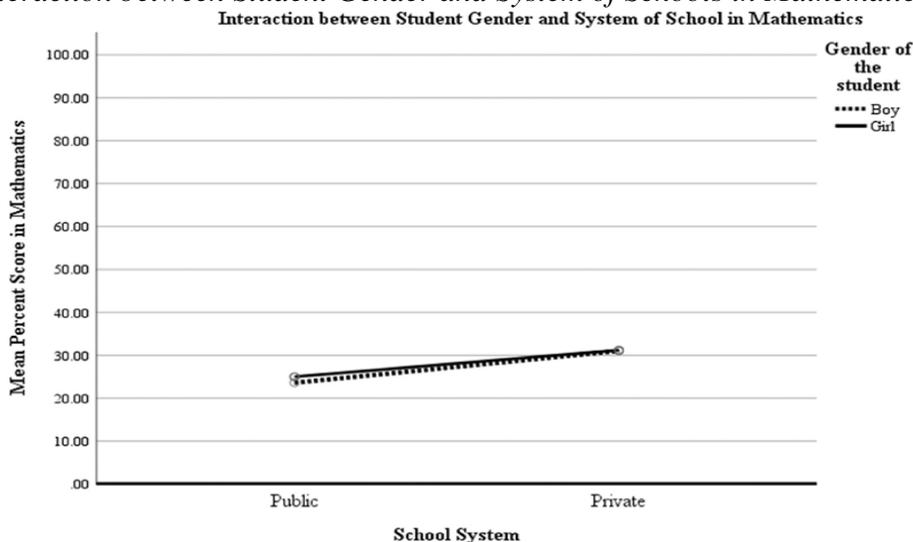
interaction effect of student gender and school system for mathematics and science achievement.

Table 2: Results of two-way ANOVA for Students' Mathematics and Science Performance by Gender and School System

Source	Sum of square	df	Mean square	F	p	Effect size (eta square)
Mathematics						
Gender	2176.442	1	2176.442	9.735	0.002	0.001
School system	168226.948	1	168226.948	752.475	0.001	0.047
Gender*system	1435.451	1	1435.451	6.421	0.011	0.000
Error	3429258.735	15339	223.565			
Science						
Gender	25599.355	1	25599.355	109.635	0.001	0.007
School system	381496.794	1	381496.794	1633.847	0.001	0.097
Gender*system	219.992	1	219.992	0.942	0.332	ns
Error	3568520.849	15283	233.496			

In mathematics, there was a significant main effect of both gender (F= 9.735, p<0.01) of students and system of school (F = 752.475, p<0.01) on students' performance. Further, as depicted in Figure 1, there was a significant interaction effect between the school system and gender on students' performance in Mathematics. Gender differences within each system of school helped to understand the pattern further. The results indicated that girls from public schools have significantly performed better in mathematics than their counterparts' boys (p< 0.05). Similarly, girls enrolled in private schools came at par to boys in private schools (p>0.05). This interplay indicates that it is not simply the gender of students that brings variations in performance, but the system of school equally contributes. More specifically, when there are equal opportunities in terms of school access, then there would be higher chances for girls to perform either better than or equal to boys in Mathematics. In other words, girls can compete with boys or even perform better (evident from within public school comparison) in Mathematics given that equal and enough opportunities were provided to them.

Figure 1: *Interaction between Student Gender and System of Schools in Mathematics*

In science, gender (F = 109.635, p<0.01) and system of schools (F=1633.847, p<0.01)

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demonstrated significant main effect on students' performance. Figure 2 shows that there was no interaction effect between system of school and gender on students' performance in Science (p>0.05). This indicates that it is the gender of students which accounts for differences in the test score, in favour of girls. In other words, girls would tend to perform significantly better in science the, regardless of the schools that they are enrolled in.

Figure 2: Interaction between Student Gender and System of Schools in Science
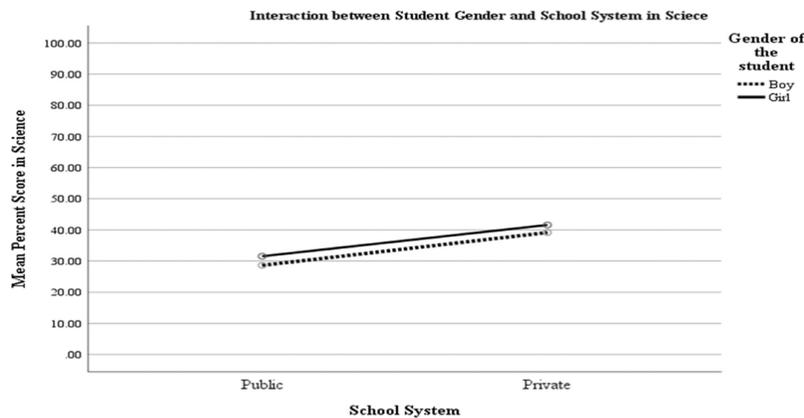
Discussion

The gender disparity in terms of performance in the core school subjects like Science and Mathematics has remained a long-standing issue in Pakistan. This study not only provided evidence related to the current status of gender disparity in academic performance in Science and Mathematics, but also dissected the differences by studying how the trends vary in different systems of schools. It is important to note that the findings presented in this paper are from a context in which girls are facing numerous challenges, such as, social and cultural constraints, economic disadvantage and discrimination in terms of access to education (Ali et al., 2023; Aslam, 2009; Jamal, 2016). Despite these challenges, the study indicates that girls have overcome the longstanding gap in Mathematics performance, which is consistent with the recent evidence of TIMSS (2019). However, there is still work to be done to ensure that girls have a strong foundation for pursuing careers in science related fields. Despite all these challenges, the existing performance of girls can serve as a source of motivation for the government, parents and other stakeholders to invest and prioritise more on girls' education in order to increase their participation in Mathematics and Science related fields. This study found that girls' performance in Science is significantly better than that of boys. The findings are consistent with a plethora of studies undertaken globally (Arora et al., 2012; Global Education Monitoring, 2022; Gonzales et al., 2008; Mullis et al., 2004) and in Pakistan (Saeed et al., 2005; Shah et al., 2020) indicating better performance of girls. The findings are encouraging for the policy makers and practitioners who are constantly striving for gender equality in students' performance. At the same time, it demands serious attention from the policy makers to sustain better performance and retain girls in science-related disciplines till higher education as well as career selection. However, evidence shows that girls' performance, as well as enrolment and completion, declines as they progress to upper grades (Ali et al., 2023; Bhutta & Rizvi, 2022). This paper shows interesting trends in Mathematics achievement by highlighting that girls came at par with boys in Mathematics performance. The findings are important for two reasons. First, it has generated new trends in Mathematics performance in favour of girls and shown contrasting results to studies that reported boys as performing better in Mathematics (Anjum & Godil, 2019; Khan et al., 2020; Kumar & Choudhury, 2022; Ullah et al., 2020). Secondly, the findings also confront the 'genetic disposition' claiming Mathematics as a subject

for boys (Butt & Dogar, 2014; Nosek et al., 2009). Thus the stereotype attitude towards poor performance of girls in Mathematics no longer holds true, at least in the context of Pakistan.

The differences in gender performance can be explained by various factors that mediate the influence of gender on student achievement. These factors include teachers' beliefs about gender differences, enrolment in public or private schools, family background, cultural aspects, and accessibility to education (Bessudnov & Makarov, 2015; Jamal, 2016; Organisation for Economic Co-operation and Development, 2019). In this study, a segregated analysis based on the school system was conducted to examine whether it contributes to gender differences in students' performance. The analysis of performance differences by gender within public and private school systems reveal interesting findings. It suggests that girls can perform equal to or better than boys when provided with equal opportunities in terms of school choice. More specifically, in public schools, girls demonstrated significantly better performance in both Mathematics and Science. Similarly, girls in private schools achieved higher scores in Science, and have an edge over boys in Mathematics. This indicates that the combination of students' gender and the school system plays a crucial role in their performance in Mathematics. Therefore, one cannot solely attribute low performance to gender alone, at least in mathematics, but must consider the influence of the school system as well. It is important to note that girls have fewer opportunities for enrolment in private schools (Aslam, 2009; Pasha, 2023), yet they can compete with boys in Mathematics, and outperform in Science. The evidence suggests that the quality of private schools in Pakistan, as determined by students' learning outcomes and teaching quality, is higher (Bhutta & Rizvi, 2022), and girls' exposure to quality education can make a significant difference.

Conclusion and Recommendations

The evidence presented in this paper contributes to understanding Pakistan's progress towards achieving SDG 4 (quality education) and SDG 5 (gender equality). Regarding SDG 4, the evidence indicates that there is a long way to go in ensuring the provision of quality education at the school level, as reflected by the low mean percentage scores for both boys and girls, indicating a "learning crisis" (Ahmad, 2022). Recent studies support this argument, particularly if Pakistan's performance is seen in TIMSS (2019), placing it at the bottom level internationally and nationally showing that over 80% of students have weak or basic understanding of Science and Mathematics concepts (Bhutta & Rizvi, 2022). This evidence puts pressure on the government to prioritise and improve the quality of education at the school level. Regarding SDG 5, the evidence suggests that Pakistan has made significant progress in raising the performance of girls in Science and Mathematics at the school level, but the question is to what extent girls are retained in science-related fields in professional life. More importantly, this paper's findings can help challenge the long-standing stereotype that girls are not good at Mathematics, especially in developing countries. By ensuring equal opportunities for girls in terms of access to education, there is a greater probability that they can pursue careers in Mathematics- related fields. Findings suggest that students' performance in elementary schools would benefit by system specific interventions at practice and policy levels. More specifically, development and implementation of gender-fair pedagogical practices and policies would lead to improved students' learning outcomes in science and mathematics. The findings also generate opportunities for future research to explore factors which contribute to gender differences and encourage educators to offer interventions to bridge this gap.

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