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Research paper

Global patterns in STEM teacher shortages: Evidence from TIMSS 2011–2023

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ABSTRACT

Shortages of mathematics and science teachers are widely cited as a global challenge, yet little is known about how these shortages evolve over time or how they are distributed across schools. Drawing on principal reports from four cycles of the Trends in International Mathematics and Science Study (TIMSS 2011–2023), this study examines longitudinal patterns in mathematics and science teacher shortages at Grades 4 and 8 across more than 40 education systems. Focusing only on countries that took part in all four cycles, we calculated the percentage of schools reporting teacher shortages and compared these rates by school socioeconomic level and urban versus rural location. Results show that teacher shortages consistently affect a majority of schools worldwide, with pooled rates typically exceeding 60% across cycles. At Grade 4, science shortages are systematically higher than mathematics shortages, affecting nearly two-thirds of schools in every cycle, whereas Grade 8 shortages display greater temporal volatility. Crucially, shortages are strongly and persistently stratified by socioeconomic status: schools serving socioeconomically disadvantaged students report shortage rates that are typically 10–20 percentage points higher than those in more advantaged schools, with persistent gaps across all cycles. By contrast, urban–rural differences are smaller and less systematic. These findings suggest that STEM teacher shortages are not merely a supply problem but a durable form of educational inequality.

1. Introduction

Teacher shortages have emerged as one of the most persistent and consequential challenges facing education systems worldwide (Organization for Economic Cooperation and Development [OECD], 2023). Across diverse national contexts, policymakers increasingly report difficulties in recruiting and retaining qualified teachers, particularly in high-demand subjects such as mathematics and science (See et al., 2022; Thompson-Lee et al., 2025). These shortages are commonly framed as workforce or supply–demand problems, linked to demographic change, teacher attrition, or insufficient training pipelines (Bleiberg & Kraft, 2022; Edwards et al., 2025). Yet such perspectives often obscure a more fundamental issue which means teacher shortages are not evenly distributed across schools or education systems but are deeply intertwined with structural inequalities (Wiggan et al., 2021).

A growing body of research documents that schools serving socioeconomically disadvantaged communities and those located in geographically marginalized areas are disproportionately affected by teacher shortages (Little & Bartlett, 2010). These patterns raise critical equity concerns, as shortages in key subjects can exacerbate existing achievement gaps and undermine students' access to high-quality instruction (Darling-Hammond & Sykes, 2003). However, despite increasing attention to teacher shortages in policy debates, empirical evidence remains fragmented. Much of the existing research relies on single-country studies, short time horizons, or aggregate indicators that mask within-system disparities. As a result, we lack a comprehensive understanding of how teacher shortages evolve over time and how they are socially and spatially distributed across schools.

Theoretically, teacher shortages can be understood through the lens of distributional justice and labor market sorting. Research on teacher labor markets demonstrates that teachers' preferences for working conditions, student composition, and school characteristics contribute to systematic sorting, with more advantaged schools typically attracting and retaining qualified teachers more easily (Bates et al., 2022, 2025; Castro, 2020). From a distributional justice perspective, unequal exposure to teacher shortages across schools represents not merely a labor market inefficiency but an inequitable distribution of educational resources and opportunities (Castro, 2020). While these studies illuminate underlying mechanisms, the aim of the present study is not to test causal theories but to provide the first longitudinal, cross-national descriptive

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evidence of where and how much STEM teacher shortages concentrate in disadvantaged schools — a descriptive foundation that is currently missing from the literature.

International large-scale assessments offer a unique but underutilized opportunity to address these gaps. The Trends in International Mathematics and Science Study (TIMSS) has collected comparable, school-level information on teacher shortages alongside student achievement for more than a decade. Importantly, TIMSS principal questionnaires capture schools' reported difficulties in staffing mathematics and science teachers, providing direct insight into institutional capacity constraints across education systems. Principal-reported shortages may reflect multiple underlying conditions, including unfilled vacancies, difficulty recruiting qualified applicants, reliance on out-of-field or underqualified teachers, or general perceptions of staffing inadequacy. While TIMSS does not distinguish among these, the measure captures institutional strain and perceived staffing constraints — a meaningful indicator of school capacity. Yet to date, this information has rarely been leveraged to examine long-term trends or equity-related disparities in teacher shortages across countries. Throughout this manuscript, we refer to "reported teacher shortages" to emphasize that our measure captures principals' perceptions of staffing difficulties rather than independently verified vacancy rates. This distinction is conceptually important for interpreting our findings.

In this study, we draw on four TIMSS cycles (2011, 2015, 2019, and 2023) to investigate global patterns in mathematics and science teacher shortages at both Grade 4 and Grade 8. Moving beyond national averages, we conceptualize teacher shortages as a distributional phenomenon and examine whether shortages are systematically concentrated in schools serving low-socioeconomic-status (SES) student populations and in rural versus urban settings. By restricting analyses to countries that participated consistently across all cycles, we provide the first longitudinal, cross-national evidence on how teacher shortages in STEM subjects have evolved over more than a decade and how inequities in exposure to shortages persist or change over time.

By reframing teacher shortages as a question of educational inequality rather than solely a labor market issue, this study contributes to ongoing debates about teacher distribution, school capacity, and opportunity structures in comparative perspective. The findings have direct implications for policy efforts aimed at mitigating staffing shortages while promoting more equitable access to qualified teachers across schools and education systems.

2. Literature review

2.1. Global patterns and inequities in teacher shortages

Teacher shortages have emerged as a prominent concern in international education policy discourse. Global monitoring reports from organisations such as the Organization for Economic Co-operation and Development and UNESCO consistently document difficulties in recruiting and retaining qualified teachers across education systems, with shortages particularly acute in science, technology, engineering, and mathematics (STEM) subjects. In these fields, competition with non-education labour markets and more demanding certification requirements tend to exacerbate teacher shortages (OECD, 2023; UNESCO, 2019, 2024). Although the magnitude and form of shortages vary considerably across countries, there is broad consensus that persistent staffing gaps threaten instructional quality and system capacity, especially during periods of demographic change, curriculum reform, or educational expansion (Symeonidis et al., 2025). Other international datasets, such as the OECD's Teaching and Learning International Survey (TALIS), have also reported widespread staffing challenges, though often at different time points or levels of aggregation. Unlike TALIS or aggregate UNESCO indicators, TIMSS offers repeated, school-level, STEM-specific shortage measures across a decade, enabling the longitudinal and equity-focused analysis that is the focus of this study.

Beyond overall levels of shortage, a substantial body of research highlights systematic inequalities in how qualified teachers are distributed across schools. Schools serving socioeconomically disadvantaged student populations are consistently more likely to experience difficulties in attracting and retaining subject-specialized teachers, a pattern observed across a wide range of national and institutional contexts (Luschei & Chudgar, 2015; Podolsky et al., 2016). These disparities are commonly linked to differences in working conditions, material resources, student composition, and school reputation. From an equity perspective, unequal exposure to teacher shortages is particularly concerning, as it may reinforce existing achievement gaps by limiting access to high-quality instruction in precisely those contexts where educational support is most needed—an issue explicitly recognised within the global education agenda of the United Nations (United Nations, n.d.-a; n.d.-b).

Geographic disparities further complicate these patterns. Rural and remote schools often face additional challenges related to limited local labour supply, professional isolation, and weaker career incentives, which can hinder both recruitment and retention (Mbunyuza-De Heer Menlah & Mays, 2010; Nkambule et al., 2014). While some studies report systematically higher shortages in rural areas, others find more mixed or context-dependent results, suggesting that urban–rural differences interact with broader policy, governance, and labour-market conditions. Importantly, evidence on spatial inequalities in teacher shortages remains uneven and is frequently confined to single-country analyses, limiting the generalisability of findings.

2.2. National evidence on STEM teacher shortages

In the United States, teacher shortages have been both large in scale and unevenly distributed. Earlier estimates suggest that in 2017 alone, schools faced a shortage of approximately 112,000 teachers, alongside more than 100,000 teachers working without appropriate certification (Sutcher et al., 2019). More recent systematic evidence confirms that these challenges persist and remain substantial. Drawing on news reports, federal administrative data, and publicly available state-level information, Nguyen et al. (2024) estimate at least 39,700 vacant teaching positions nationwide, in addition to approximately 288,000 positions filled by underqualified teachers, figures that likely underestimate the true extent of shortages.

Shortages disproportionately affect high-poverty schools, which are more likely to employ teachers with limited experience, insufficient credentials, or no formal training in the subjects they teach (García & Weiss, 2020). Policy responses have included targeted incentive programmes such as the Talent Transfer Initiative, which offered financial bonuses to high-performing teachers who moved to low-performing schools. Evaluations indicate that while such incentives temporarily increased teacher mobility and short-term retention, their effects diminished once financial support ended (Glazerman et al., 2013).

National research from other contexts highlights distinct drivers of teacher shortages. In Sweden, shortages have been linked primarily to limited supply from teacher education programmes. Lindqvist et al. (2022) reports that annual cohorts of newly qualified teachers met only a small fraction of system demand, compounded by relatively low programme completion rates. In contrast, Singapore has experienced fewer shortages, largely due to low attrition rates. Research suggests that this stability is partly attributable to Singapore's teacher education model, which requires prospective teachers to gain school-based experience prior to formal training, allowing for more informed career selection and stronger long-term commitment to the profession (Ng et al., 2018).

Subject-specific shortages are most frequently documented in STEM-related fields. For example, in New Zealand, growing demand for technology education has led many schools to rely on non-specialist teachers, with over two-thirds reporting the use of out-of-field staff to deliver technology courses (Reinsfield & Lee, 2022). Similar patterns of STEM teacher shortages have been reported in the United States (Fuentes & Bloom, 2023; Toh et al., 2006), England (Hillier et al., 2013), Croatia (Erceg et al., 2022), and across the European Union (Davydovskaia et al., 2021). Reinforcing this picture, comparative evidence from the Eurydice network indicates that 35 of 43 European education systems reported teacher shortages in 2021, suggesting that teacher shortages persist across much of Europe despite sustained investment in teacher recruitment and retention (Eurydice, 2021).

Recent syntheses further underscore the complexity of teacher shortage measurement and policy response. Nguyen et al. (2024) provide a systematic analysis of teacher shortages in the United States, identifying substantial regional and subject-specific variation, including tens of thousands of vacant positions and a large population of underqualified teachers. Their findings emphasize persistent challenges in data quality and comparability, alongside the need for more targeted and equity-oriented policy interventions. Extending beyond single-country analyses, Gorard et al. (2024) employ a Qualitative Comparative Analysis (QCA) across 18 countries, demonstrating that teacher shortages emerge from constellations of interacting factors, including labour-market conditions, teacher workload, school resources, and societal perceptions of teaching. Their results highlight that no single policy lever is sufficient and that national responses must be understood within broader institutional and economic contexts.

2.3. Conceptual gaps and the role of international assessments

Taken together, national research reveals substantial cross-country variation in the severity, subject focus, and distribution of teacher shortages, as well as in the policy strategies adopted to address them. Shortages in STEM subjects are relatively well documented, with evidence pointing to persistent recruitment and retention challenges and mixed effectiveness of commonly used policy interventions, particularly financial incentives (Thompson-Lee, See, & Klassen, 2023). These shortages reflect subject-specific labor market dynamics and teacher supply differs markedly by subject due to more demanding certification requirements and the greater availability and attractiveness of non-teaching career options for STEM-qualified individuals. Over the past two decades, exits from the STEM teaching workforce have consistently outpaced new certifications, and mathematics and science are repeatedly identified as critical shortage areas across education systems (Goldhaber et al., 2015; McVey & Trinidad, 2019). At the school level, teacher shortages are also unevenly distributed, with schools reporting substantially greater difficulty filling STEM positions than positions in general or elementary education, reflecting competition within localized labor markets (Cowan et al., 2016; James et al., 2022). However, comparative and longitudinal evidence on how STEM teacher shortages are distributed across schools serving different socioeconomic populations and how these patterns evolve over time across education systems remains limited. Greater attention to these distributional dynamics is essential for understanding long-term trends and for identifying policy approaches that may be transferable across national contexts.

International large-scale assessments such as the Trends in International Mathematics and Science Study (TIMSS) offer a valuable yet underutilized resource for addressing these gaps. By combining internationally comparable measures of school conditions with repeated cross-sectional designs, TIMSS enables analyses that are both longitudinal and cross-national. Leveraging this potential, the present study contributes to the literature by documenting long-term trends in STEM teacher shortages and by situating these shortages within broader patterns of socioeconomic and geographic inequality across education systems. To our knowledge, this is the first study to document longitudinal, cross-national trends in STEM teacher shortages while explicitly examining their socioeconomic and geographic distribution across schools.

2.3.1. Research questions

In this study, we draw on four cycles of TIMSS (2011, 2015, 2019, and 2023) to investigate shortages of teachers specialized in mathematics and science at both Grade 4 and Grade 8 across more than 40 education systems worldwide, including national and sub-national systems. Beyond documenting overall patterns, we examine whether teacher shortages are unevenly distributed across schools by socioeconomic context and geographic location.

Specifically, we address the following research questions:

1. International trends: How have reported shortages of mathematics and science teachers evolved over time across participating education systems between 2011 and 2023?
2. Socioeconomic inequality: Within education systems, how do teacher shortages differ between schools serving low- and high-socioeconomic-status (SES) student populations, and how have these disparities changed over time?
3. Geographic inequality: Within education systems, how do teacher shortages differ between rural and urban schools, and how have these differences evolved across TIMSS cycles?

3. Methods

3.1. Data sources

We analyzed data from the International Association for the Evaluation of Educational Achievement's (IEA) Trends in International Mathematics and Science Study (TIMSS). In addition to assessing students' mathematics and science achievement at Grades 4 and 8, TIMSS collects extensive background information on students' demographic characteristics and learning environments, as well as on teachers' characteristics and instructional practices, and principals' leadership practices and school-level conditions (IEA, 2017; Mullis et al., 2020).

For participating education systems, TIMSS employs a two-stage stratified sampling design, in which schools are first selected with probabilities proportional to size, followed by the random selection of one or two intact classrooms within each sampled school (Foy & LaRoche, 2017). This design ensures nationally representative samples of students at each target grade.

In the present study, analyses were restricted to countries that participated consistently across all selected TIMSS cycles and for which comparable principal questionnaire data on school demographic composition and teacher shortage indicators were available. The final analytic sample comprises four TIMSS cycles (2011, 2015, 2019, and 2023) and includes only countries that participated in all four cycles. The resulting sample consists of 43 countries at Grade 4 and 31 countries at Grade 8 (Table S1, S2 and S3 available in the Appendix). The four TIMSS cycles span 2011 to 2023. The 43 education systems at Grade 4 include countries from North and South America (e.g., United States, Chile), Europe (e.g., England, Germany, Finland, Italy), Asia and the Middle East (e.g., Japan, Korea, Singapore, United Arab Emirates), and elsewhere (e.g., Australia, New Zealand, South Africa). The Grade 8 sample includes a subset of 31 of these systems. Across all cycles, the analytic sample comprises approximately 8000–8700 schools at Grade 4 and 6000–6400 schools at Grade 8 per cycle.

3.2. Measures

Our main outcome variables are two binary indicators capturing whether a school experiences a shortage of teachers specialized in mathematics and science. These variables were derived from principals' responses to four-category items in the TIMSS questionnaire, which asked about the extent of teacher shortages ("Not at all," "A little," "Some," and "A lot"). Responses of "Not at all" were coded as 0, indicating no mathematics or science teacher shortage, whereas responses of "A little," "Some," or "A lot" were coded as 1, indicating the presence of a mathematics or science teacher shortage (Table S5 and S6, available in the Appendix). To assess whether dichotomization distorted the underlying information, we calculated polychoric correlations between our binary shortage indicators and the original 4-point ordinal items. Correlations ranged from 0.996 to 0.999 across all cycles and subjects, indicating that the binary measure preserves virtually all of the original information. This strongly supports the use of dichotomization for cross-country and cross-cycle comparability.

To examine differences in mathematics and science teacher shortages by school socioeconomic context and urbanicity, we focused on two key school-level background characteristics. School socioeconomic status (SES) was operationalized using principals' reports of the proportion of students from socioeconomically disadvantaged backgrounds. Schools in which more than 50% of students were classified as socioeconomically disadvantaged were coded as low-SES schools (0), whereas schools with 50% or fewer disadvantaged students were coded as high-SES schools (1) (Table S7 and S8, available in the Appendix).

School urbanicity was derived from principals' reports of the population size of the area in which the school is located. Schools situated in areas with a population of more than 100,000 inhabitants were classified as urban schools and coded as 1, whereas schools located in areas with 100,000 or fewer inhabitants were classified as rural schools and coded as 0 (Rees et al., 2017; UN Statistics Division, 2017). This choice is also consistent with widely used NCES locale classifications, which distinguish metropolitan areas based on Core Based Statistical Area thresholds (≥100,000), alongside micropolitan and noncore areas (NCES, 2023). (Table S9 and S10, available in the Appendix).

This approach to SES classification (using a >50% threshold of principal-reported disadvantaged students) and urbanicity classification (using a 100,000 population threshold to distinguish rural from urban schools) follows the same operationalization strategy used in recent research published in this journal (O'Rafferty et al., 2026).

Item descriptions for both Grade 4 and Grade 8, across all study years, are provided in Table S4 in the Appendix.

3.3. Analytical strategy

Our analytical strategy proceeded in four steps to examine levels, trends, and inequalities in mathematics and science teacher shortages across TIMSS cycles, grades, and school contexts.

First, we estimated pooled prevalence rates of mathematics and science teacher shortages separately for Grade 4 and Grade 8 in each TIMSS cycle (2011, 2015, 2019, and 2023). For each country–grade–-year combination, school-level weighted proportions were computed using the TIMSS school weights (SCHWGT) to ensure national representativeness. These country-specific estimates were then aggregated to obtain pooled shortage rates across participating countries within each cycle. To quantify uncertainty, 95% confidence intervals were calculated around pooled estimates, accounting for between-country variability.

Second, to examine temporal trends, we compared pooled shortage rates across cycles within each grade and subject. This descriptive trend analysis allowed us to assess whether shortages remained stable, increased, or declined over time, and whether patterns differed between mathematics and science. Given the repeated cross-sectional design of TIMSS and changes in participating countries across cycles, analyses were restricted to countries that participated consistently in all four cycles to ensure comparability over time.

For each TIMSS cycle t, grade g, and subject s (mathematics or science), pooled teacher shortage rates were estimated using school-level weighted proportions. Let i index schools in the pooled dataset (restricted to countries participating in all cycles within each grade), y_igts denote a binary indicator equal to 1 if school i reports a teacher shortage in subject s and 0 otherwise, and w_igt denote the TIMSS school weight (SCHWGT).

The pooled teacher shortage rate is defined as:

$$\hat{p}\_gts = \left(\sum\_i w\_igt\ y\_igts\right) \Big/ \left(\sum\_i w\_igt\right)$$

where the summations are taken over all schools with non-missing shortage information for the corresponding grade, cycle, and subject.

To quantify uncertainty around the pooled estimate, we derived a standard error using the weighted proportion and an effective sample size reflecting the distribution of school weights:

$$SE\left(\hat{p}\_gts\right) = \sqrt{\left[\hat{p}\_gts\left(1-\hat{p}\_gts\right) \Big/ \left(\left(\sum\_i w\_igt\right)\hat{2} \Big/ \sum\_i w\_igt\hat{2}\right)\right]}$$

Using this standard error, 95% confidence intervals were constructed as:

$$CI\,95\% = \left[max\left(0, \hat{p}\_gts - 1.96 \cdot SE\left(\hat{p}\_gts\right)\right), min\left(1, \hat{p}\_gts + 1.96 \cdot SE\left(\hat{p}\_gts\right)\right)\right]$$

All estimates are reported as percentages.

Third, we investigated socioeconomic disparities in teacher shortages by estimating pooled shortage rates separately for low-SES and high-SES schools, based on principals' reports of student socioeconomic composition. For each cycle, grade, and subject, we calculated weighted proportions of schools experiencing teacher shortages within each SES group. Differences between low-SES and high-SES schools were then examined descriptively to assess both the magnitude and persistence of SES-related gaps over time.

Fourth, we examined urban–rural differences in teacher shortages using the school urbanicity classification derived from principals' reports of local population size. Analogous to the SES analyses, pooled shortage rates were estimated separately for urban and rural schools by cycle, grade, and subject. This allowed us to assess whether spatial disparities in teacher shortages were systematic, grade-specific, or subject-specific, and whether they changed across TIMSS cycles.

To examine disparities in teacher shortages by school context, the pooled estimation procedure was repeated separately for school subgroups defined by socioeconomic status and urbanicity. Let I_igtk be an indicator equal to 1 if school i belongs to subgroup k (e.g., low SES vs. high SES, or rural vs. urban) and 0 otherwise.

The subgroup-specific pooled shortage rate is defined as:

$$\hat{p}\_gtsk = \left(\sum\_i w\_igt\ I\_igtk\ y\_igts\right) \Big/ \left(\sum\_i w\_igt\ I\_igtk\right)$$

Standard errors and confidence intervals for subgroup estimates were computed using the same weighted-proportion approach described above, applied within each subgroup. All analyses were conducted separately for Grades 4 and 8 and for mathematics and science.

All analyses were conducted separately for Grade 4 and Grade 8, and for mathematics and science, to reflect differences in teacher labor markets, certification requirements, and instructional organization between primary and lower secondary education. Throughout, results are presented as weighted percentages to facilitate substantive interpretation and cross-cycle comparison. Detailed item mappings, country participation, and variable harmonization procedures are documented in the Appendix.* All analyses were conducted using R (Posit Team, 2024). To account for TIMSS's complex sampling design (two-stage stratified cluster sampling), we applied the TIMSS school weights (SCHWGT) for all point estimates. For variance estimation, we used the jackknife repeated replication (JRR) method with the TIMSS replicate weights (JKZONE and JKREP), following IEA's technical guidelines (Foy & LaRoche, 2017). This approach accounts for clustering within schools and stratification at the country level, ensuring accurate standard errors and confidence intervals for both pooled estimates and subgroup comparisons.

4. Results

RQ1. Trends in Reported Mathematics and Science Teacher Shortages Across Grades 4 and 8

At Grade 8, pooled teacher shortage rates were similarly substantial but displayed greater fluctuation over time (see Fig. 1). In mathematics, shortages remained relatively stable at just over 60% in 2011 (60.9%, 95% CI [57.3, 64.5]) and 2015 (60.7%, 95% CI [57.1, 64.3]), followed by a modest decline in 2019 (60.3%, 95% CI [54.2, 66.5]) and a more pronounced decrease by 2023 (54.4%, 95% CI [48.0, 60.7]). Science shortages exhibited a different trajectory. After beginning at a comparable level in 2011 (61.0%, 95% CI [57.3, 64.6]), science shortages declined slightly in 2015 (58.9%, 95% CI [55.2, 62.6]) before rising sharply in 2019 to 67.1% (95% CI [61.2, 73.1]). By 2023, science shortages fell markedly to 52.3% (95% CI [45.9, 58.7]), converging with mathematics at historically lower levels.

Across TIMSS cycles, teacher shortages at Grade 4 were consistently high in both mathematics and science (see Fig. 2). In mathematics, the pooled shortage rate was 63.3% in 2011 (95% CI [60.6, 65.9]), declined slightly to 61.0% in 2015 (95% CI [58.1, 63.9]), and then increased again to 62.8% in 2019 (95% CI [59.9, 65.7]) and 63.2% in 2023 (95% CI [60.1, 66.2]). A similar but systematically higher pattern was observed for science. Science teacher shortages reached 68.0% in 2011 (95% CI [65.4, 70.6]), remained elevated in 2015 at 66.5% (95% CI [63.7, 69.3]), and persisted at comparable levels in 2019 (67.2%, 95% CI [64.3, 70.0]) and 2023 (66.8%, 95% CI [63.8, 69.8]). Overall, science shortages consistently exceeded mathematics shortages at Grade 4 across all cycles.

The pooled estimates mask substantial cross-national heterogeneity (see Appendix Figures S1–S2 for full country trajectories). For example, at Grade 4 in 2023, the percentage of schools reporting science teacher shortages ranged from 15.5% in Georgia to 87.4% in Hong Kong SAR. Similarly, at Grade 8 in 2023, mathematics shortages ranged from 13.8% in the Republic of Korea to 81.8% in Malaysia (2019 data show even higher levels, with Malaysia reaching 95.4% in both mathematics and science). Some systems showed remarkable stability over time: Singapore maintained consistently low shortages at Grade 8 (e.g., 22.9% in mathematics in 2019), while others such as Turkey reported persistently high shortages exceeding 80% in multiple cycles. These contrasts illustrate that while shortages are widespread globally, their prevalence and trajectories vary considerably across education systems.

RQ2. Trends in Reported Mathematics and Science Teacher Shortages Across Grades 4 and 8 by School SES

At Grade 4, clear and persistent socioeconomic inequalities in teacher shortages were observed across all TIMSS cycles in both mathematics and science (see Fig. 3). In mathematics, schools serving low-SES student populations consistently reported substantially higher teacher shortages than high-SES schools. In 2011, the pooled shortage rate in low-SES schools was 70.6%, compared to 59.7% in high-SES schools. Although shortages in low-SES schools declined to 64.7% in 2015, they increased again in 2019 (68.4%) and rose sharply by 2023, reaching 78.2%. In contrast, shortages in high-SES schools remained relatively stable over time, fluctuating narrowly between approximately 58% and 61%, with a slight decline in 2023. As a result, the SES gap in mathematics teacher shortages not only persisted across cycles but remained substantial in the most recent assessment. A similar pattern emerged in science, with consistently higher shortages in low-SES schools across all cycles. Science teacher shortages in low-SES schools declined from 73.7% in 2011 to 68.4% in 2015, before increasing again in 2019 (73.2%) and reaching a peak of 81.1% in 2023. By comparison, high-SES schools experienced lower and more stable science shortages, remaining close to 65% between 2011 and 2019 and declining to 61.9% by 2023. Across all cycles, the SES gap in science was larger than in mathematics, indicating a pronounced concentration of science teacher shortages in socioeconomically disadvantaged primary schools.

At Grade 8, SES-related disparities in teacher shortages were even more pronounced (see Fig. 3). In mathematics, shortages in low-SES schools were high and increased steadily from 71.3% in 2011 to 78.9% in 2019, before declining to 66.3% in 2023. Despite this recent decrease, mathematics teacher shortages in low-SES schools remained substantially higher than those in high-SES schools in every cycle. High-SES schools, in contrast, exhibited consistently lower and declining shortage rates, decreasing from 54.0% in 2011 to 49.2% in 2023. This resulted in a large and persistent SES gap throughout the period. Science shortages at Grade 8 followed a similar but more volatile trajectory.

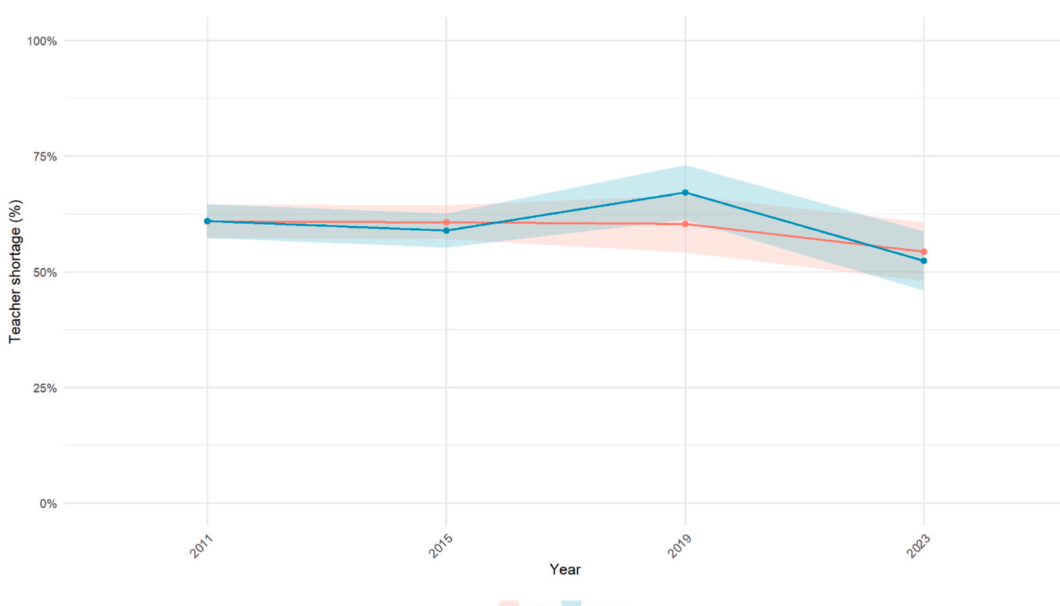

Fig. 1. Pooled percentage of mathematics and science teacher shortages across TIMSS cycles for Grade 8. Estimates are based on principal reports and are weighted using school weights (SCHWGT). Shaded areas represent 95% confidence intervals. The analysis includes 31 education systems that participated in all TIMSS cycles from 2011 to 2023. *Science shortages showed greater volatility than mathematics, rising sharply in 2019 before declining markedly by 2023.

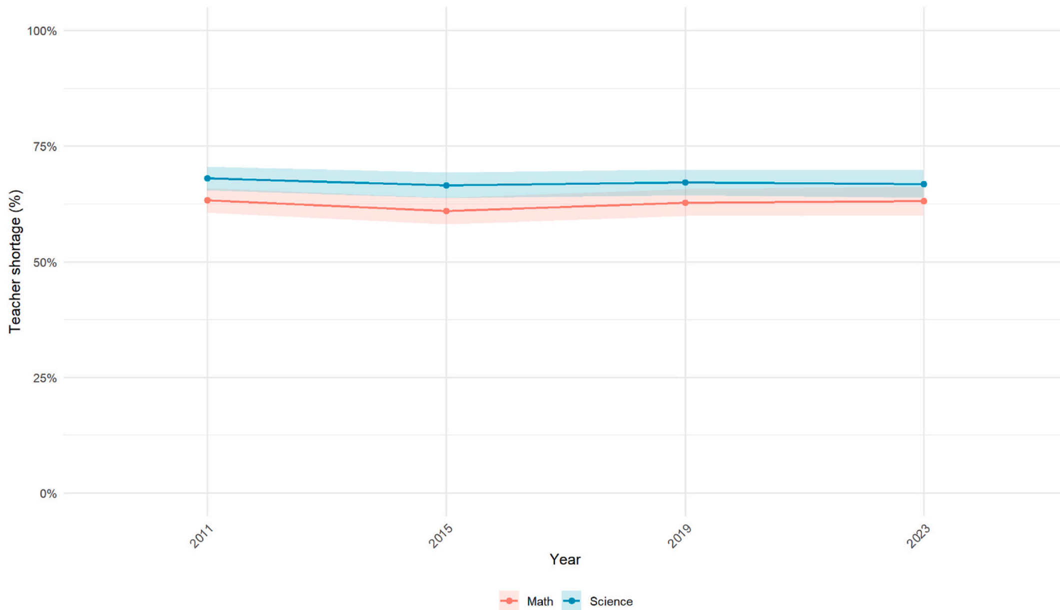

Fig. 2. Pooled percentage of mathematics and science teacher shortages across TIMSS cycles for Grade 4. Estimates are based on principal reports and are weighted using school weights (SCHWGT). Shaded areas represent 95% confidence intervals. The analysis includes 43 education systems that participated in all TIMSS cycles from 2011 to 2023. *Science shortages consistently exceeded mathematics shortages across all cycles, affecting nearly two-thirds of schools.

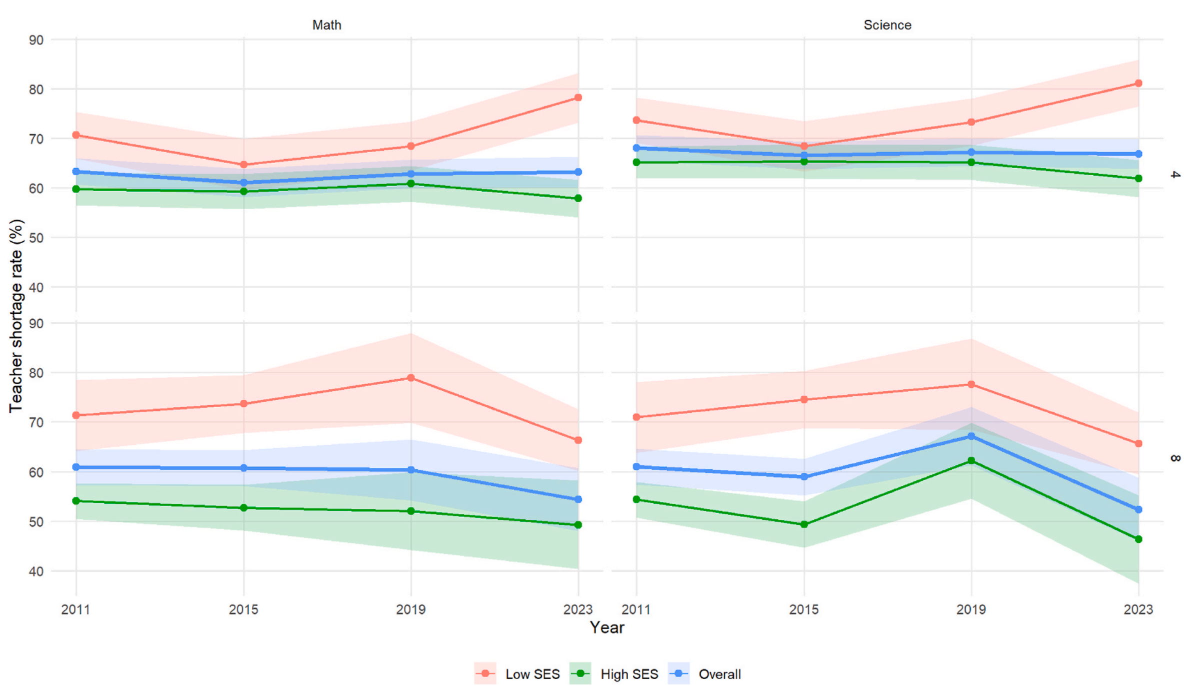

Fig. 3. Pooled trends in mathematics and science teacher shortages by school socioeconomic status (SES), TIMSS 2011–2023 (Grade 4: N = 43 countries; Grade 8: N = 31 countries). Notes. Estimates are weighted by SCHWGT; shaded bands indicate 95% confidence intervals; "Overall" represents pooled estimates across all schools within each grade-year sample. Low-SES and high-SES groups are defined using the study's SES classification; only education systems participating in all cycles are included.*Low-SES schools consistently reported higher teacher shortages than high-SES schools, with persistent gaps across all cycles, particularly at Grade 8.

Low-SES schools reported very high shortages across cycles, increasing from 70.9% in 2011 to 77.6% in 2019, before declining to 65.6% in 2023. High-SES schools again experienced markedly lower shortages, with rates falling from 54.3% in 2011 to 49.3% in 2015, rising temporarily in 2019 (62.2%), and declining to 46.3% in 2023. Although some convergence occurred in the final cycle, science teacher shortages remained consistently higher in low-SES schools across all cycles at the lower secondary level.

SES-based disparities also varied considerably across education systems. For example, at Grade 8 in 2023, the gap in mathematics teacher shortages between low-SES and high-SES schools ranged from near parity in some systems (e.g., United Arab Emirates, where low-SES schools reported 73.0% and high-SES schools 54.7%) to dramatically wider gaps in others (e.g., Italy, where low-SES schools reported 73.1% compared to 72.5% in high-SES schools — conversely, some systems like Turkey showed low-SES shortages of 69.4% versus 74.8% in high-SES schools, indicating that disadvantage does not uniformly predict higher shortages across all contexts). Appendix Tables S7–S8 provide full country-specific SES trajectories.

RQ3. Trends in Reported Mathematics and Science Teacher Shortages Across Grades 4 and 8 by Urbanicity

At Grade 4, urban–rural differences in teacher shortages were present but less systematic than SES-based disparities (see Fig. 4). In mathematics, shortages in rural and urban schools were broadly comparable across cycles, with the direction and magnitude of the gap varying over time. Rural schools reported a shortage rate of 63.7% in 2011, declining to 58.4% in 2015, before increasing again in 2019 (62.5%) and remaining at a similar level in 2023 (62.3%). Urban schools followed a different trajectory, with shortages increasing from 62.3% in 2011 to 66.4% in 2015, then declining slightly in 2019 (63.4%) and rising again in 2023 (64.9%). Overall, no consistent urban–rural gradient emerged in Grade 4 mathematics. In science, a similar pattern was observed. Rural science teacher shortages declined from 68.6% in 2011 to 64.0% in 2015, before increasing slightly in 2019 (66.5%) and remaining elevated in 2023 (65.8%). Urban schools exhibited higher shortages in some cycles, particularly in 2015 (72.1%), but lower or comparable shortages in others. Across cycles, the urban–rural gap in science at Grade 4 varied in both size and direction, indicating the absence of a stable spatial pattern.

At Grade 8, urban–rural differences became more pronounced and consistent (see Fig. 4). In mathematics, rural schools reported higher teacher shortages than urban schools in every cycle. Rural shortages declined gradually from 63.8% in 2011 to 55.3% in 2023, while urban shortages remained consistently lower, decreasing from 53.6% in 2011 to 52.7% in 2023. Although shortages declined for both groups over time, the rural disadvantage persisted throughout the period. Science shortages at Grade 8 displayed a similar pattern. Rural schools reported higher shortages than urban schools in all cycles, with a particularly sharp increase in 2019, when rural shortages peaked at 70.9%, compared to 57.7% in urban schools. By 2023, shortages declined substantially in both settings, converging at just above 52%. Despite this convergence, rural schools consistently experienced higher science teacher shortages across the full period.

Urban–rural heterogeneity was equally pronounced. At Grade 8 in 2023, mathematics teacher shortages in rural schools ranged from 12.9% in the Republic of Korea to 87.3% in Morocco, while urban schools ranged from 11.0% in Korea to 83.5% in Malaysia. In some systems, rural shortages substantially exceeded urban shortages (e.g., Australia: 80.5% rural vs. 50.9% urban), while in others the pattern reversed or showed minimal differences. Appendix Tables S9–S10 provide full country-specific urbanicity trajectories.

To formally test whether observed changes over time were statistically significant, we estimated country fixed effects regression models with robust standard errors (Table 1). Results revealed no statistically significant global linear trends in reported teacher shortages for most grade-subject combinations ($p > 0.05$), with the exception of Grade 4 in 2015, which showed a temporary decline of approximately 8 percentage points ($p < 0.05$). The largest source of variation was between countries rather than across cycles, suggesting that global shortage rates have

Table 1
Country fixed effects regression results for teacher shortages.

Variable	Grade 4 Math	Grade 4 Science	Grade 8 Math	Grade 8 Science
SES (High vs. Low)	−6.79* (3.09)	−5.92* (2.70)	−10.42** (3.56)	−10.62** (3.88)
Urbanicity (Urban vs. Rural)	−8.11* (3.20)	−8.72** (2.98)	−8.11* (3.20)	−8.72** (2.98)
Year2015	−7.94* (3.40)	−7.95* (3.46)	−2.53 (4.62)	−1.83 (4.73)
Year2019	−3.55 (3.17)	2.45 (2.88)	2.35 (3.61)	3.49 (4.00)
Year2023	0.52 (3.86)	−0.63 (3.41)	−3.38 (4.23)	−5.43 (4.59)
N (observations)	230	230	119	119

Note: Coefficients are unstandardized β with robust standard errors in parentheses. Country fixed effects included but not shown. Reference year: 2011. Reference SES: Low SES. Reference urbanicity: Rural.
**$p < 0.01$, $p < 0.05$.

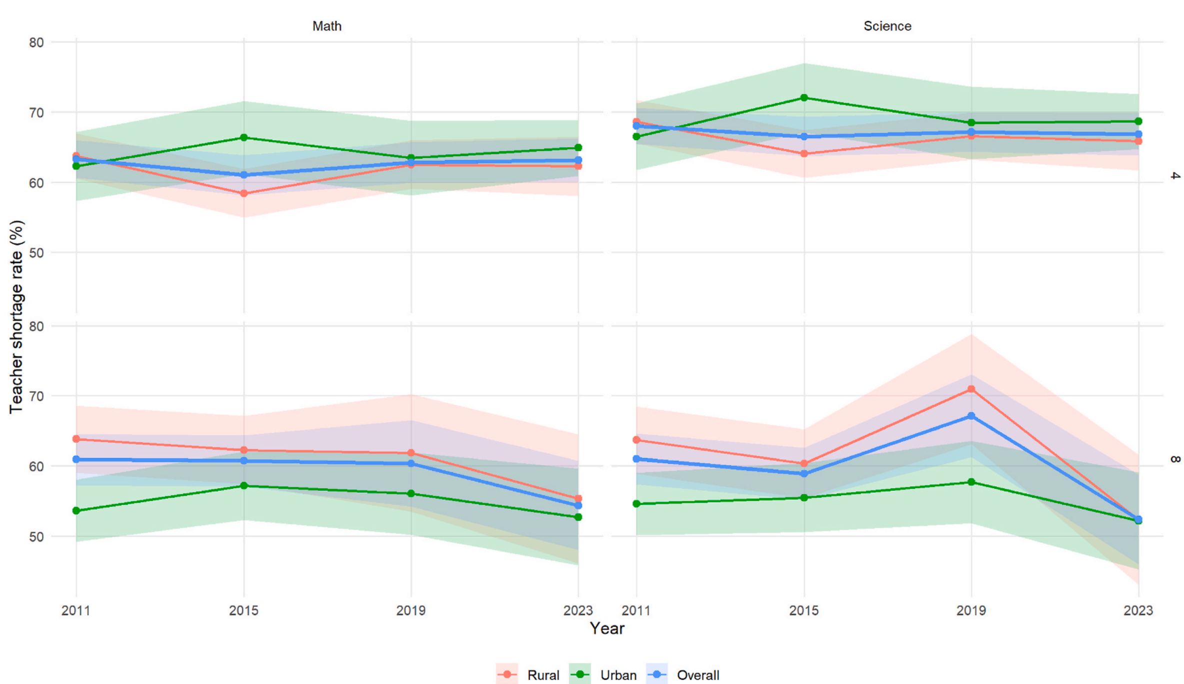

Fig. 4. Pooled trends in mathematics and science teacher shortages by school urbanicity, TIMSS 2011–2023 (Grade 4: N = 43 countries; Grade 8: N = 31 countries). Notes. Estimates are weighted by SCHWGT; shaded bands indicate 95% confidence intervals; "Overall" represents pooled estimates across all schools within each grade–year sample. Urban and rural classifications follow the TIMSS school location indicator; only education systems participating in all cycles are included.*
*Urban–rural differences were smaller and less systematic than SES disparities, though rural schools showed higher shortages at Grade 8.

remained relatively stable over the 2011–2023 period.

Country fixed effects regression models confirmed that low-SES schools report significantly higher teacher shortages than high-SES schools across both grades (Table 1). At Grade 8, the SES gap was approximately 10–11 percentage points (mathematics: $\beta = -10.42$, $p = 0.004$; science: $\beta = -10.62$, $p = 0.007$). At Grade 4, the gap was smaller but still significant (mathematics: $\beta = -6.79$, $p = 0.029$; science: $\beta = -5.92$, $p = 0.029$). However, SES × year interaction terms were not statistically significant for any cycle ($p > 0.05$ for all specifications), indicating that the magnitude of socioeconomic disparities did not significantly widen or narrow over the study period.

Country fixed effects regression models showed that urban schools report significantly lower teacher shortages than rural schools (Table 1). At Grade 8, the urban-rural gap was approximately 8–9 percentage points (mathematics: $\beta = -8.11$, $p = 0.012$; science: $\beta = -8.72$, $p = 0.004$). Similar patterns were observed at Grade 4 (mathematics: $\beta = -8.11$, $p = 0.012$; science: $\beta = -8.72$, $p = 0.004$). Urbanicity × year interaction terms were not statistically significant ($p > 0.05$ for all cycles), suggesting that the rural disadvantage persisted without meaningful change over time.

Taken together, the results indicate that SES-based inequalities in teacher shortages are stronger, more persistent, and more systematic than urban–rural differences, particularly at Grade 8 and in science. While urbanicity patterns vary by grade and cycle, socioeconomic disadvantage is consistently associated with substantially higher teacher shortages across subjects and over time. These findings suggest that teacher shortages are closely linked to broader structural inequalities, with socioeconomically disadvantaged schools bearing a disproportionate and enduring burden of teacher shortages.

5. Discussion

This study provides longitudinal, cross-national evidence that mathematics and science teacher shortages, as reported by principals, remain widespread across TIMSS education systems from 2011 to 2023. Two patterns stand out. First, shortages are persistently high at both Grade 4 and Grade 8, with subject- and grade-specific dynamics. Second, and more consequential for equity, shortages are not evenly distributed across schools. Socioeconomic disparities are large, systematic, and enduring, whereas urban–rural differences are more modest and less stable, particularly at Grade 4. Together, these results support a central implication that STEM teacher shortages should be understood not only as a workforce capacity problem but also as a distributional inequality problem within education systems.

A key finding is the consistently elevated level of science shortages at Grade 4 across cycles, exceeding mathematics shortages in every TIMSS wave. This pattern suggests that primary-level science staffing may be particularly vulnerable, potentially reflecting constraints in science specialization, limited subject-specific preparation, or organizational arrangements in which science instruction depends on fewer staff with relevant training. In contrast, Grade 8 shortages display greater volatility over time, especially in science, where a notable increase in 2019 is followed by a marked decline by 2023. Although this study does not identify causal drivers, the volatility is consistent with a subject-specific labor market that is sensitive to policy changes, supply shocks, or shifts in school staffing strategies. Importantly, the overall decline by 2023 at Grade 8, alongside convergence between mathematics and science, suggests that shortages are not immutable; systems may be able to reduce shortages over time, though not necessarily in ways that narrow inequality. While causal claims are not possible, this decline may plausibly reflect post-pandemic staffing adjustments, targeted policy reforms implemented during 2020–2022, or shifts in principal reporting practices following COVID-19 disruptions. Alternatively, it could be influenced by changes in labor market conditions or temporary improvements in teacher supply. These possibilities warrant further investigation in future research.

The most consistent and policy-relevant pattern concerns socioeconomic stratification. Across both grades and both subjects, schools serving socioeconomically disadvantaged student populations report substantially higher shortages, with gaps that persist across cycles and are especially pronounced at Grade 8. This finding aligns with longstanding evidence that teacher labor markets are structured by unequal working conditions and opportunity structures that disadvantaged schools often face greater recruitment challenges due to higher workloads, fewer resources, more difficult teaching conditions, and lower perceived career rewards (Hanushek et al., 2004; Lankford et al., 2002). What this study adds is long-term, cross-national descriptive evidence showing that such stratification is not episodic which means it is a stable feature of many systems' staffing landscapes, even when overall shortage levels fluctuate. In practical terms, the burden of STEM staffing constraints falls disproportionately on students in disadvantaged schools, raising concerns about unequal access to subject-specialized instruction and the possibility that such patterns may reinforce existing achievement inequalities, though direct evidence on this link is beyond the scope of the present study.

Urban–rural disparities in teacher shortages appear more contingent and grade-specific rather than uniformly structured. At Grade 4, differences between rural and urban schools fluctuate in both direction and magnitude across cycles, indicating no stable spatial gradient in the pooled trends. In contrast, at Grade 8, rural schools more consistently report higher shortages in both mathematics and science. This pattern aligns with prior evidence that teacher retention tends to be lower in rural and urban schools than in suburban settings, reflecting differential participation in local teacher labor markets (Cowen et al., 2012; Hanushek et al., 2004; Jacob, 2007; Lankford et al., 2002; Miller, 2012). The greater persistence of rural shortages at the lower secondary level suggests that geographic constraints may become more salient as instructional organization intensifies, subject specialization increases, and staffing requires more narrowly credentialed teachers. Rather than operating as a uniform disadvantage across schooling levels, "place" may therefore shape shortages through its interaction with teacher mobility, labor market attachment, and the institutional demands of lower secondary education.

These findings point toward a policy agenda that moves beyond increasing the overall supply of teachers and instead prioritizes equitable distribution. If shortages are socially patterned, broad pipeline expansions alone are unlikely to reduce the unequal exposure of disadvantaged schools to staffing constraints, particularly in STEM fields, where certification requirements are more demanding and alternative career opportunities are more attractive (Hansen et al., 2019; West, 2013). Policies may therefore need to combine STEM recruitment and preparation strategies with targeted incentives, improved working conditions, and stronger retention supports in disadvantaged contexts. Likewise, where rural disadvantages emerge, especially at Grade 8, policies that address geographic isolation, housing, professional support, and career progression may be necessary to stabilize staffing. For example, financial incentives such as salary supplements or loan forgiveness could be targeted specifically to STEM teachers who commit to working in low-SES schools. Alternative certification pathways could be designed to address rural Grade 8 science shortages. Improvements in working conditions — such as reduced administrative burden, access to mentoring, and stronger school leadership — could be prioritized in disadvantaged contexts (see also Thompson-Lee et al., 2025). While these approaches must be adapted to national contexts, the international evidence highlights that broad, untargeted supply-side policies alone are unlikely to narrow equity gaps.

Several limitations should be acknowledged. First, teacher shortages are measured using principals' self-reports and therefore capture perceived rather than objectively verified staffing conditions. These perceptions may reflect vacancies, recruitment difficulties, out-of-field teaching, or general staffing concerns, but TIMSS does not allow us to distinguish among these. These perceptions may be shaped by local expectations, institutional norms, or policy environments, potentially introducing systematic differences in reporting across systems and over time. Moreover, what constitutes a "shortage" may differ systematically across education systems. Principals' perceptions are shaped by local norms, staffing regulations, policy expectations, and cultural contexts. For example, a principal in a system with chronic staffing difficulties might report "a little" shortage as negligible, whereas a principal in a system with generally adequate staffing might report the same level as a serious concern. While TIMSS item wording is standardized, these underlying reference points likely vary across countries, potentially affecting cross-national comparability. As Di Pietro (2023) notes, different teacher accreditation systems across countries make the development of common comparative indicators for teacher shortages "extremely challenging." We therefore interpret our pooled estimates as reflecting relative patterns and rank-orderings rather than absolute, objective measures of vacancy rates.

Second, shortage indicators were dichotomized from ordinal response categories to facilitate cross-country comparability and interpretability. While this approach aligns with prior international research and supports clear communication of trends, it necessarily obscures finer distinctions in shortage severity that may be meaningful within specific contexts. Additionally, our SES classification using a >50% threshold of principal-reported disadvantaged students may not be perfectly equivalent across countries, as definitions of "disadvantaged" likely vary by national context. Similarly, the 100,000 population threshold for urbanicity, while transparent and instrument-aligned, may not capture meaningful differences in local labor markets across all countries (e.g., Singapore, where the entire population is classified as urban). However, this operationalization follows established practice in the field (O'Rafferty et al., 2026), and within-country comparisons (low-SES vs. high-SES schools; rural vs. urban schools) remain valid as the classification is applied consistently across schools within each education system. Third, although the study documents both pooled international trends and country-specific patterns (reported in the appendix and supplementary materials), the analyses remain descriptive and do not explicitly model the policy, labor-market, or governance mechanisms that may underlie observed changes over time. As such, the study is not designed to identify causal drivers of teacher shortages or to evaluate the effectiveness of particular national interventions. Finally, the analyses rely on school-weighted estimates that ensure representativeness of schools within each education system. However, the focus on aggregate trends limits the ability to assess within-school dynamics or teacher-level processes, such as differential assignment of qualified teachers within schools, which may further contribute to inequalities in staffing (Edwards et al., 2025).

Overall, by documenting both persistent shortage levels and strong socioeconomic stratification in shortages across multiple TIMSS cycles, this study shifts the conversation from whether STEM teacher shortages exist to where they concentrate and for whom they matter most.

6. Conclusion

Across four TIMSS cycles, principals' reports indicate that mathematics and science teacher shortages remain widespread at both Grade 4 and Grade 8, with distinct subject- and grade-specific trajectories. The most consistent finding, however, is distributional, shortages are systematically concentrated in socioeconomically disadvantaged schools across cycles, grades, and subjects, whereas urban–rural differences are weaker and more context-dependent. These patterns suggest that addressing STEM teacher shortages requires more than increasing supply. It requires policies explicitly designed to reduce the unequal exposure of disadvantaged schools to staffing constraint through targeted recruitment, retention supports, and improvements in working conditions in the schools most affected. Theoretically, these findings reframe STEM teacher shortages as a distributional equity issue rather than merely a labor market or supply-side problem. Practically, they suggest that policymakers must move beyond aggregate recruitment efforts and instead target resources to socioeconomically disadvantaged schools, where shortages are most severe and persistent. Without explicit equity-oriented interventions, even successful efforts to increase overall teacher supply will likely leave the deepest staffing gaps unchanged. Future research should connect shortage patterns to student outcomes, teacher quality, and policy interventions to identify which strategies reduce shortages while also narrowing educational inequality.

Declaration of competing interest

The author declares that there are no known financial or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tate.2026.105657.

Data availability

Data will be made available on request.

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