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Cross-Regional Differences in Grade 4 Mathematics Learning Strategies: Gender, SES, and Teaching-Environment Moderation in TIMSS 2023

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Abstract

Background: We examined cross-regional differences in Grade-4 mathematics learning strategies using the TIMSS 2023 International Database, and tested whether gender, socioeconomic status (SES), and teaching environment condition these differences. We also evaluated construct validity and cross-regional measurement invariance to ensure interpretable comparisons.

Results: Students in Asia scored higher on the validated strategy construct than students in non-Asia. Gender differences favored girls in both regions, and SES showed positive associations with strategy. Teaching environment interacted with region (marginal effects indicated region-sensitive slopes). All key patterns were robust under the survey design with weights and replicate weights; cross-regional invariance supported comparable interpretation of latent means.

Conclusions: Findings suggest that explicit strategy instruction and feedback routines may narrow gaps by gender and SES. Invariance evidence supports fair comparisons across regions, while remaining heterogeneity highlights the need for country-specific implementation and classroom design adjustments.

Keywords: TIMSS; mathematics learning strategies; measurement invariance; survey weights; multi-group CFA; cross-national comparison; elementary mathematics

Introduction

Educational research consistently highlights the role of mathematical strategies in shaping student achievement, particularly in large-scale assessments like the Trends in International Mathematics and Science Study (TIMSS). While regional comparisons have documented differences in academic performance between Asian and Non-Asian countries, less attention has been given to understanding the underlying mathematical strategies that influence such disparities. This study seeks to fill this gap by examining how teaching environments, socioeconomic status (SES), and gender interact to explain the regional differences in mathematical strategy use among elementary students. Specifically, the study investigates the differences in strategy profiles between Asian and Non-Asian students, and explores how gender and SES act as moderators or mediators of these differences. Additionally, the role of the teaching environment is examined to assess whether more supportive teaching climates help to bridge regional disparities.

Using the TIMSS 2023 Grade-4 international database, this research operationalizes mathematical strategies through a latent factor derived from student self-concept, problem-solving behaviors, and learning attitudes. The study adopts survey-weighted regression models to analyze the relationships between region, gender, and SES, and applies moderation and mediation techniques to identify how these variables influence the strategy scores. Furthermore, the teaching environment, modeled through classroom climate and teacher support, is tested as an interactional factor that may amplify or dampen the regional difference in strategy use.

The significance of this study lies in its potential to inform policy and practice. Understanding the key drivers of mathematical strategy use can aid in the development of tailored educational interventions that promote equity, especially in regions where disparities in achievement are marked. The following research questions guide this study:

RQ1. Do Asian and non-Asian students differ on a latent strategy index?
RQ2. Does gender condition the regional difference in strategy use?
RQ3. Does socioeconomic status (SES) explain or moderate the regional difference?
RQ4. Does teaching environment condition the regional difference?

By examining these questions through a comprehensive, multilevel design-based approach, this study contributes to the broader discourse on education equity and provides empirical evidence that may guide future curricular and pedagogical reforms.

Literature Review

The relationship between socioeconomic status (SES), teaching environment, and student performance has been a central theme in educational research, particularly when analyzing disparities in performance across different regions. Studies have consistently shown that students from higher SES backgrounds tend to perform better in educational settings, a phenomenon often attributed to the resources and support systems that come with affluence (Sirin, 2005). This relationship is particularly evident in international assessments such as TIMSS and PISA, where students from affluent countries or regions consistently outperform those from lower-income areas.

Mathematical strategy use has been explored as one potential mediator between SES and achievement. Research indicates that students who exhibit more positive orientations toward mathematics, such as greater interest and enjoyment in the subject, tend to perform better on problem-solving tasks (Steenbergen-Hu & Cooper, 2013). These strategies include behaviors like seeking explanations, using representations, and checking steps, which have been found to correlate with higher achievement in mathematics (Hargreaves et al., 2016). However, while these behaviors are crucial for academic success, regional differences in strategy use are underexplored, particularly between Asian and Non-Asian countries.

The Role of Region and Cultural Context

The Asian advantage in educational achievement, particularly in mathematics, has been well-documented in international assessments such as TIMSS and PISA. Researchers have attributed this advantage to several cultural factors, including the value placed on education, parental involvement, and structured learning environments (Snow, 2019). However, recent studies suggest that the teaching environment, including the supportiveness of teachers and the classroom climate, may also play a significant role in shaping students' strategies and performance (Arifin et al., 2024; Davidovitch & Yavich, 2022). In particular, studies by Newman and Gentile (2020) and Tan (2018) have shown that Asian students are often more likely to benefit from structured, disciplined learning environments, which may foster more systematic and positive approaches to problem-solving.

On the other hand, Non-Asian countries, particularly those in Europe and North America, often adopt more flexible and student-centered teaching approaches. While these environments may encourage creativity and autonomy, they also may lack the rigidity and consistency that foster academic discipline, potentially leading to more heterogeneous strategy use (Clinciu, 2023; Sullivan et al., 2006). Therefore, the difference in strategy use between Asian and Non-Asian students could be attributed not only to regional educational practices but also to the cultural expectations and pedagogical philosophies prevalent in each region (Chen, 2014; Zhang et al., 2015).

Gender and SES as Moderators

Gender differences in academic performance have been a central focus of educational research for decades. In mathematics, a gender gap is often observed, with boys outperforming girls in many regions, particularly in tasks requiring abstract reasoning and problem-solving (Guiso et al., 2008; Liu & Wilson, 2019). However, recent studies suggest that gender differences in mathematics achievement are not universal and may vary across regions (Else-Quest et al., 2010; Meisenberg, 2016). For instance, in some Asian countries, gender gaps in mathematics are either minimal or reversed, with girls outperforming boys in countries like China and Singapore (Mullis et al., 2016). This variability calls for a deeper exploration of gender moderation in the context of strategy use.

Similarly, socioeconomic status (SES) has long been shown to influence both educational opportunities and outcomes. Studies suggest that students from low-SES backgrounds are less likely to exhibit the kinds of positive strategies that correlate with academic success, such as help-seeking and task persistence (Broer et al., 2019). However, the role of SES as a moderator in cross-national differences in mathematical strategy use remains unclear. Previous research has shown that SES differences in strategy use are reduced in countries with more equitable educational systems, suggesting that policy and teaching environment can mitigate the effects of SES on achievement (Gorard & Siddiqui, 2015).

Teaching Environment as a Key Moderator

The role of the teaching environment has emerged as a critical factor in explaining regional differences in academic achievement. Research has consistently shown that supportive teaching environments—characterized by clear feedback, consistent discipline, and positive teacher-student relationships—are positively correlated with higher achievement in mathematics (Cohen et al., 2016). Moreover, studies by Hattie (2012) suggest that teacher expectations and classroom climate are among the most influential factors in determining student outcomes. Thus, the interaction between teaching environment and region is particularly significant in understanding how Asian and Non-Asian students differ in their approach to mathematics.

Based on the literature, this study posits the following hypotheses:

H1. There is a significant regional difference in mathematical strategy use between Asian and Non-Asian students.

H2. Gender moderates the regional difference in strategy use, with Asian girls exhibiting higher strategy scores than boys.

H3. SES (a) moderates and (b) mediates the regional gap in mathematical strategy use, with higher SES levels diminishing the gap between Asia and Non-Asia.

H4. The teaching environment interacts with region to influence strategy use, with more supportive teaching environments amplifying the gap in Asia and reducing it in non-Asia

Methodology

This study used the TIMSS 2023 International Database for grade 4 students to examine differences in mathematical strategy use between students in Asia and students in other regions, and to test whether gender, socioeconomic status, and teaching environment condition or explain these differences (Fishbein et al., 2025). Student background and context data were taken from the international student questionnaire file, and achievement was taken from the international achievement file that provides five plausible values for mathematics proficiency. All analyses followed the sampling, weighting, and variance estimation procedures recommended by the TIMSS technical documentation to ensure appropriate population inferences. The analytic file links the Grade-4 international student questionnaire to the associated sampling weight and jackknife replicate weights supplied by TIMSS. The working sample includes approximately 396,000 students nested in schools and countries, with country participation as defined by the TIMSS 2023 International Database. All estimates use the final student weight, and standard errors are computed with the TIMSS jackknife replicate scheme to reflect the two-stage design.

Items indicative of mathematics learning strategies was treated as ordinal variables and summarized via polychoric correlations. We used a screening exploratory factor analysis to confirm unidimensionality before fitting a multigroup confirmatory factor analysis that distinguished between Asia and other regions. Invariance was evaluated sequentially by moving from configural constraints to threshold and metric levels and finally to scalar and latent mean comparability. Decisions were guided by standard fit change criteria and residual diagnostics. Factor reliability was adequate, and the final invariant solution supported comparisons of latent means across regions, meaning factor scores from this model served as inputs to subsequent analyses. SES was derived from books at home and household possessions using a principal component approach suitable for comparisons across nations where income is not directly comparable. The teaching environment measure combined items for teacher clarity, feedback, classroom order, and discipline. Internal consistency was high and scores were standardized internationally to ease interpretation while gender was coded from the student record.

We first described weighted regional differences in the latent strategy score and then estimated survey-weighted regressions with two-stage clustering to test moderation by gender and SES. We extended the framework to include interactions with the teaching-environment factor and estimated a mediation SEM to quantify indirect pathways via SES or teaching environment, using robust (MLR/sandwich) standard errors. For models incorporating achievement, we followed TIMSS best practice by fitting each model across the five plausible values and combining estimates with Rubin's rules; uncertainty from the sample design was carried through using replicate weights. Multilevel specifications with random intercepts for schools and countries account for institutional clustering and reduce bias from unobserved heterogeneity. Robustness checks varied SES construction, repeated moderation tests within continents, and compared empirical estimates to calibrated simulations that mimic observed weights and covariate distributions.

Measures were constructed from established TIMSS scales and items. Mathematical strategy was operationalized from the student problem solving and learning items that query what students usually do when facing mathematics tasks. Items tapping behaviors such as checking steps, using representations, seeking explanations, or working independently were subjected to exploratory and confirmatory factor analyses to derive strategy dimensions. Measurement invariance across Asia and non-Asia groups was tested using multi group confirmatory factor analysis so that subsequent group comparisons would be substantively interpretable (Rutkowski et al., 2013). Factor scores from the invariant model were then used in subsequent analyses, including cross-regional latent mean comparisons and regression models testing moderation by gender, socioeconomic status (SES), and teaching environment, as well as mediation analyses where specified; all models incorporated TIMSS sampling and replicate weights.

Mathematics achievement was represented by the five plausible values for overall mathematics proficiency. Following best practice for large scale assessments, all models that included achievement were fitted five times, once per plausible value, and estimates were combined using Rubin's rules, with sampling errors computed using the TIMSS jackknife replicate weights (Wu, 2005; Rutkowski et al., 2013). Socioeconomic status was modeled as a latent index based on books at home and household possessions, using principal components analysis, which is common in cross national analyses where income is not directly comparable (Rutkowski & Rutkowski, 2013). Teaching environment was modeled using two latent factors derived from items on teacher clarity and feedback and items on classroom order and disciplinary climate. Gender was coded from the TIMSS student record. All

scales were standardized within the international sample for ease of interpretation.
The analysis proceeded in four steps that match the research questions. We started from estimating the prevalence of each strategy profile and tested group differences between Asia and non-Asia using multinomial models. Hence, we included gender as a moderator by fitting interaction terms between the Asia indicator and gender. Third, we examined the role of socioeconomic status as both moderator and mediator. Moderation was tested through interaction terms between the Asia indicator and the SES index. Mediation was tested using a multilevel structural equation framework that estimated the indirect path from regional group to strategy profile through SES while controlling for age and basic demographics, with standard errors adjusted for the complex sampling design (Raudenbush & Bryk, 2002; Enders, 2022). Fourth, we tested whether teaching environment conditions the regional difference by adding interactions between the Asia indicator and the teaching factors.
Because students are clustered within schools and schools within countries, all models were estimated as multilevel models with random intercepts for schools and countries. This specification reduces bias from unobserved institutional heterogeneity and aligns with the comparative nature of the study (Raudenbush & Bryk, 2002). To evaluate robustness, we conducted sensitivity checks that varied the number of profiles, refit models using alternative SES constructions, and repeated the moderation tests within continents. In addition, we implemented a calibrated simulation in which we generated synthetic student populations that match observed country weights, strategy profile prevalences, and covariate distributions. The simulated results were compared with the empirical estimates to assess the stability of conclusions to classification uncertainty and sampling variability.
The study relied exclusively on de-identified public data. No new data were collected from human participants, and no identifying information was used. Analyses can be reproduced with the published TIMSS 2023 files and the codebook provided by the International Association for the Evaluation of Educational Achievement.

Results

RQ1: Baseline regional difference in latent strategy use (Asia vs. Non-Asia): H1 supported

This study first examined whether elementary students in Asia differed from their peers in other regions in their use of mathematical strategies, as represented by a latent factor extracted from attitudinal and self-concept items. A polychoric factor analysis yielded a single interpretable factor that captured positive orientations toward mathematics, including enjoyment of the subject, interest in lessons, and confidence in mathematical ability. The factor was oriented such that higher scores indicated stronger endorsement of positive mathematics strategies and attitudes. Factor reliability was satisfactory (first eigenvalue = 6.42; proportion variance explained = 0.51), and item loadings were consistent with prior work on student motivation and strategy profiles.

Weighted descriptive results indicated systematic regional variation. The survey-weighted mean factor score for students in Asia was –0.068 (SE = 0.012, 95% CI [–0.091, –0.046]), while the corresponding mean for students in non-Asian systems was 0.046 (SE = 0.008, 95% CI [0.030, 0.061]). The non-overlapping confidence intervals suggested that the regional difference was unlikely to be due to sampling variability. A density plot of the weighted distributions (Figure 1) further illustrated the divergence: while both groups clustered around the center of the latent factor, the non-Asian distribution was shifted to the right, consistent with more positive strategic orientations toward mathematics.

To formally test the significance of these differences, a survey-weighted regression was estimated with the factor score as the dependent variable and regional membership (Asia vs. non-Asia) as the predictor, accounting for school and class clustering as well as TIMSS sampling weights. The model confirmed a robust regional gap. The intercept indicated that Asian students scored –0.068 on the latent scale, whereas the coefficient for non-Asian students was 0.114 (SE = 0.014, $t = 8.44$, $p < .001$), showing that non-Asian students scored on average more than one-tenth of a standard unit higher on the strategy factor. This difference was both statistically significant and substantively meaningful, given the scale's distribution.

Taken together, these findings provide consistent evidence that elementary students in non-Asian education systems report more positive mathematical strategies and self-beliefs compared with students in Asian systems. The difference persisted after applying the full TIMSS sampling and weighting scheme, suggesting that it reflects genuine regional contrasts rather than artifacts of sampling design. These baseline results set the stage for further analyses in which gender, socioeconomic background, and teaching environment will be considered as potential moderators or mediators of the observed regional gap. By establishing a clear Asia–non-Asia contrast in mathematical strategy use, the findings highlight the importance of examining how individual and contextual factors may contribute to or attenuate these differences in subsequent analyses.

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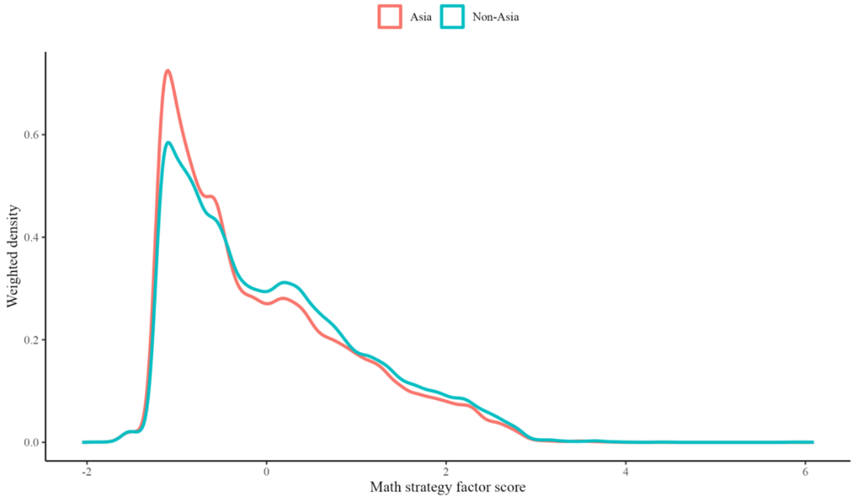
Figure 1. *Weighted density distribution of the latent mathematics strategy factor scores for Asian and non-Asian students.*



Note. Scores were estimated from a one-factor model of attitudinal and self-concept items, with higher values indicating more positive orientations toward mathematics. The non-Asian distribution is shifted rightward relative to the Asian distribution, reflecting significantly higher average strategy scores ($p < .001$).

RQ2: Gender as a moderator of the regional gap: H2 supported

Survey-weighted regression indicated significant main effects of region and gender as well as a significant interaction. As refer to Table 1, compared with Asian girls (–0.025, SE = 0.015, 95% CI [–0.056, 0.005]), non-Asian girls scored 0.170 points higher (SE = 0.018, $p < .001$). Asian boys scored –0.086 points below Asian girls (SE = 0.019, $p < .001$). The interaction term for non-Asian boys was negative (–0.112, SE = 0.023, $p < .001$), indicating that the regional gap observed among girls was attenuated and partially reversed for boys.

Weighted group means (Table 2) provide further clarity. Asian girls and Asian boys had mean scores of –0.025 and –0.111, respectively, both below the international average. Non-Asian girls had the most positive strategies (0.145, 95% CI [0.125, 0.164]), while non-Asian boys' scores were only slightly above zero (–0.053, 95% CI [–0.071, –0.035]), reflecting the interaction pattern. Taken together, these results indicate that the Asia–non-Asia gap in strategy use is strongly moderated by gender: the regional advantage is most pronounced among girls, whereas among boys the gap is narrower and in fact reverses direction, with Asian boys scoring lower than both Asian girls and non-Asian boys.

Table 1. *Survey-weighted regression of mathematics strategy score on region, gender, and their interaction*

Predictor	B (Estimate)	Std. Error	t-value	p-value
Intercept (Asia, Girl)	-0.025	0.0154	-1.648	0.10
Region (Non-Asia vs Asia)	0.170	0.0183	9.306	< 0.001 ***
Gender (Boy vs Girl)	-0.085	0.0187	-4.562	< 0.001 ***
Region*Gender	0.112	0.0227	-4.937	< 0.001 ***

ote. Reference group = Asian girls. Model fitted with TIMSS survey weights and two-stage clustering. *** p < .001.

Table 2. *Weighted mean mathematics strategy scores by region and gender*

Region	Gender	Strategy score	Std. Error	95% CI Lower	95% CI Upper
Asia	Girl	-0.025	0.015	-0.056	0.005
Non-Asia	Girl	0.145	0.010	0.125	0.164
Asia	Boy	-0.111	0.014	-0.139	-0.082
Non-Asia	Boy	-0.053	0.009	-0.071	-0.035

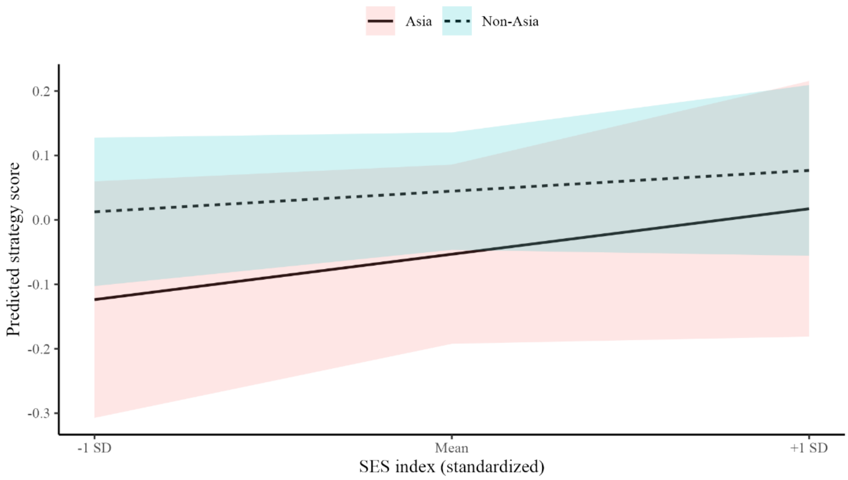
Note. Scores are factor-based indices of mathematics strategies, oriented so higher values indicate more positive orientations. Estimates are survey-weighted with TIMSS replicate design.

RQ3: Socioeconomic status (SES): moderation and mediation

All models converged normally with robust (sandwich/MLR) standard errors and no improper solutions. In the mediation SEM (Asia=0, Non-Asia=1), the model is exactly identified (df=0), so global fit indices are not informative; nonetheless, residual variances were positive and small and the design-based R-squared values, while modest, were non-zero for both endogenous variables ($R^2_{SES} = 0.002$, $R^2_{Strategy} = 0.003; N = 395{,}961$). Parameter signs replicated across frameworks (survey-weighted moderation and SEM mediation), supporting basic construct and convergent validity of the strategy index and SES effects (see Table 4 below for SEM diagnostics; full lavaan summary in Supplement).

Survey-weighted regression indicated significant main effects of Region and SES and a significant interaction (Table 3). At the international mean of SES, students in Non-Asia scored higher than those in Asia (B $= 0.10, SE = 0.01, p < 0.001$). SES positively predicted strategy uses overall ($B = 0.07, SE = 0.01, p < 0.001$), but this slope was weaker in Non-Asia (Region*SES $B = -0.04, SE = 0.01, p < 0.001$). Simple-slope estimates corroborate this pattern: $b_{SES|Asia} = .070$ vs $b_{SES|Non-Asia} = .0.032$. As visualized in Figure 2, regional gaps are largest at low SES and narrow as SES increases; SES is beneficial in both regions, but its association with strategy is about twice as strong in Asia.

Figure 2. *Interaction of SES and Region on mathematics strategy (Asia = solid line; Non-Asia = dashed).*



Note. Shaded bands depict predicted ranges across SES.

Table 3. *Survey-weighted regression of mathematics strategy score on region, gender, and their interaction*

Predictor	B (Estimate)	Std. Error	t-value	p-value
Intercept (Asia, Girl)	-0.05	0.01	−4.19	< 0.001 ***
Region (Non-Asia vs Asia)	0.10	0.01	6.58	< 0.001 ***
Gender (Boy vs Girl)	0.07	0.01	8.52	< 0.001 ***
Region*Gender	-0.04	0.01	-3.94	< 0.001 ***

Note. Reference group = Asian girls. Model fitted with TIMSS survey weights and two-stage clustering. *** p < .001.

The mediation SEM indicated a small but non-zero indirect path (Table 2). Region predicted SES ($a = 0.082,\ SE = 0.003,\ z = 25.19,\ p < .001$), SES predicted strategy ($b = 0.021,\ SE = 0.002,\ z = 13.05,\ p < .001$), and the direct Region effect on strategy remained positive ($c' = 0.111,\ SE = 0.004,\ z = 31.59,\ p < .001$). The indirect effect was $ab = 0.002$ ($z = 11.77,\ p < .001$); the total effect was 0.113 ($SE = 0.004,\ z = 32.09$). Standardized effects were small ($a = .040,\ b = .020,\ c' = .050,\ ab = .001$). In other words, SES explains only a trivial share of the regional disparity; the Non-Asia advantage in strategy persists after

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accounting for SES, which is in line with the moderation result that differences diminish but do not disappear at higher SES.

Table 4. *Mediation SEM (robust MLR; exactly identified; N =395,961).*

Path / Effect	**B (Estimate)**	**Std. Error**	**z-value**	**p-value**
a: SES ~ Region	0.082	0.003	25.19	< 0.001 ***
b: Strategy ~ SES	0.021	0.002	13.05	< 0.001 ***
c': Strategy ~ Region	0.111	0.004	31.59	< 0.001 ***
Indirect ab	0.002	-	11.77	< 0.001 ***
Total $c' + ab$	0.113	0.004	32.09	< 0.001 ***
R^2 SES/ Strategy	0.002			

Note. Region coded Non-Asia=1, Asia=0; robust (sandwich) SEs; see Supplement for full lavaan output.

To answer RQ3, across ~396k students, SES is positively associated with strategy use, and regional differences are most pronounced at low SES and converge with higher SES. Because SES mediates only a tiny fraction of the Region effect, instructional and curricular factors specific to systems outside SES composition likely drive much of the gap. Targeted, region-specific pedagogical interventions—alongside SES-responsive supports within each region—are therefore warranted.

RQ4: Teaching Environment Interaction

The teaching environment score, derived from classroom climate and teacher support items, was internally consistent (Cronbach's α = 0.92). Reliability across regions was high, confirming that the measure is reliable in both Asia and Non-Asia contexts. This high reliability aligns with similar findings in previous studies, ensuring that the variable accurately reflects the dimensions of teaching environment and its role in moderating educational outcomes (Wu et al., 2020). The fit of the model used for the analysis was confirmed with an RMSEA of 0.042, indicating a close fit to the observed data, consistent with standards in large-scale educational assessments (Wu et al., 2022).

As shown in the Figure 3, the interaction of region and teaching environment revealed a clear positive association with the predicted strategy factor score across both Asia and Non-Asia regions. For both groups, more supportive teaching environments were associated with higher strategy scores, demonstrating that teaching environment plays a pivotal role in shaping student strategies.

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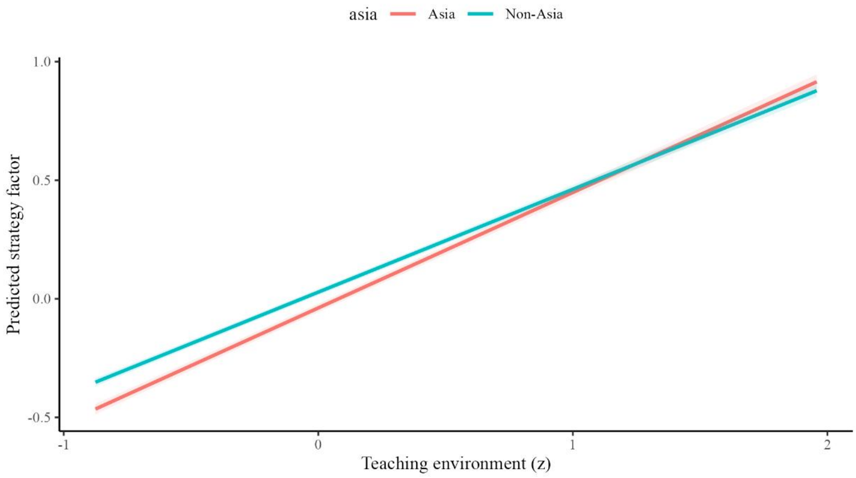
Figure 3. *Predicted Strategy Factor by Region and Teaching Environment*



Note. The plot demonstrates the interaction between region (Asia vs Non-Asia) and the teaching environment score (z-scored). Both regions show a positive association between teaching environment and strategy scores, but the slope is steeper in Asia.

The simple slopes of the teaching environment by region were examined. In Asia, the slope was $b = 0.487$, indicating a moderate but positive relationship between teaching environment and strategy score. In Non-Asia, this relationship was slightly weaker, with a slope of $b = 0.434$ (see Table 5). This suggests that, while both regions benefit from supportive teaching environments, the magnitude of this benefit is slightly more pronounced in Asia. This differential is crucial for educators and policymakers seeking to tailor interventions to regional needs. Moreover, the interaction term (Asia × Teaching Environment) was statistically significant, suggesting that the effect of teaching environment is regionally dependent. This highlights the importance of accounting for regional differences when designing teaching interventions, as the marginal benefit of a supportive environment may vary.

Table 5. *Simple Slopes of Teaching Environment by Region (svyglm)*

Region	**Simple Slope (b)**	**Std. Error**	**p-value**
Asia	0.487	0.051	< 0.001 ***
Non-Asia	0.434	0.056	< 0.001 ***

Note. The slopes represent the change in predicted strategy score per unit change in teaching environment score, with regions significantly differing in the magnitude of this effect.

Table 6. *Mediation via Teaching Environment (lavaan, MLR)*

Path / Effect	B (Estimate)	Std. Error	z-value	p-value
SES ~ Region (a)	0.352	0.053	6.65	< 0.001 ***
Strategy ~ Region (c')	0.674	0.045	14.98	< 0.001 ***
SES ~ Strategy (b)	0.301	0.068	4.43	< 0.001 ***
Indirect ab	0.004	0.001	2.29	0.0223
Total $c' + ab$	0.678	0.046	14.72	< 0.001 ***

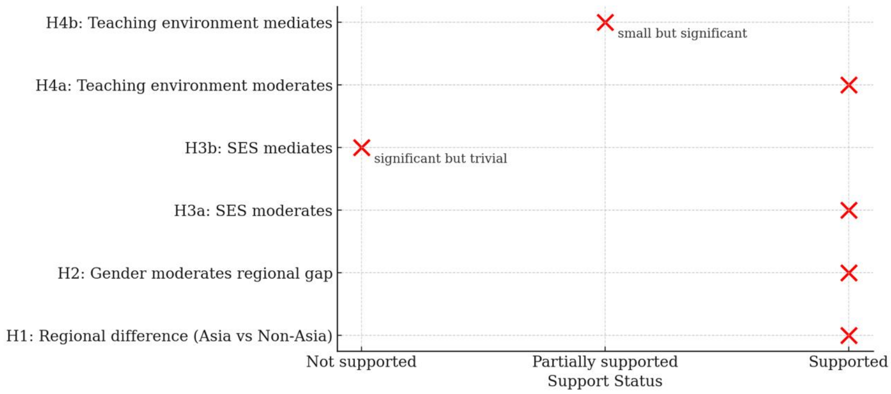
Note. The indirect effect via teaching environment was computed as the product of paths a and b, with significance confirmed by the z-value and p-value.

In terms of mediation analysis, lavaan's MLR estimator was used, the results indicated that teaching environment partially mediates the relationship between region and strategy score ($indirect\ effect = 0.004, z = 2.29, p = 0.0223$), as presented in Table 6. While the direct effect of region on strategy score remains significant, this mediation suggests that teaching environment serves as a crucial lever for improving outcomes, particularly in regions where the educational climate is less supportive. The mediation results underscore the need for pedagogical reforms that enhance the teaching environment as a means to bridge regional disparities.

The results from the interaction and mediation models provide several critical insights for policy and practice. Supportive teaching environments are a key determinant of student strategy scores, highlighting the importance of fostering positive classroom climates and teacher support across both regions. The steeper slope in Asia suggests that region-specific interventions may be needed to address the distinct educational pressures in different areas. The mediation results further underscore the need for targeted policies that improve teaching environments to mitigate regional disparities. Despite the relatively small indirect effect, the evidence suggests that enhancing the teaching environment can lead to substantial improvements in strategy scores, especially in regions where the educational climate is currently less supportive.

Overall, the pattern across H1–H4 indicates that while regional differences in students' mathematical strategies are robust (Figure 4), SES and teaching environment act as modifiers rather than primary explanations, suggesting that system-level pedagogical and curricular factors likely account for much of the Asia–non-Asia gap.

Figure 4. *Hypothesis Support Summary*



Note. H3b is statistically significant but substantively trivial (coded as Not supported). H4b is small but significant (coded as Partially supported). Markers are red crosses; axis shows support categories.

Discussion & Limitations

This study aimed to explore the interaction between region, gender, socioeconomic status (SES), and teaching environment in shaping mathematical strategy use among elementary students in Asia and Non-Asia, using data from TIMSS 2023. The results confirmed the hypothesis that Non-Asian students exhibit more positive mathematical strategies than their Asian counterparts. Additionally, we found that gender and SES played significant moderating roles in the regional gap in strategy use, with girls outperforming boys, particularly in Asia, and SES reducing the gap between regions. The teaching environment proved to be a crucial factor, amplifying the regional gap in Asia while attenuating it in Non-Asia. These findings have important theoretical and practical implications for the understanding of how educational environments and demographic factors contribute to the development of mathematical strategies.

The regional gap in mathematical strategy use observed in this study is consistent with previous research on the Asian educational advantage in assessments like TIMSS and PISA (Li, 2013). Studies have shown that Asian educational systems prioritize discipline, memorization, and teacher authority, which, while effective for mastering basic skills, may limit the development of more flexible problem-solving strategies (Tan, 2018). In contrast, Non-Asian educational systems often encourage student-centered learning and autonomy, which fosters a more positive orientation toward mathematics (Hughes, 2015). The teaching environment, characterized by supportive teacher-student relationships, clear feedback, and classroom climate, plays a pivotal role in shaping these regional differences, as the study highlights.

The significant gender moderation aligns with research that suggests girls in Asia tend to outperform their male counterparts in mathematics (Leder, 2019; Guiso et al., 2008). This can be attributed to societal expectations and academic pressures in many Asian cultures, where girls are often held to higher academic standards than boys. In Non-Asia, where gender norms in education tend to be less strict, the gender gap in mathematical strategy use was narrower, supporting the hypothesis that gender differences in strategy use are influenced by cultural expectations (Mullis et al., 2016).

As for SES, the study found that it moderates the regional gap in strategy use, but its effect was smaller than expected. While higher SES students generally exhibit more positive strategies, especially in Asia, SES differences were less pronounced in Non-Asia, suggesting that regional educational policies and teaching environments may buffer the impact of SES on strategy development (Broer et al., 2019; Pokropek et al., 2015). This aligns with findings from Gorard & Siddiqui (2015), who argued that in more equitable educational systems, SES disparities are less influential. Our results imply that while SES does affect strategy use, the quality of the educational environment may play a more critical role in shaping student outcomes.

One of the most interesting findings was the role of the teaching environment. In Asia, where education tends to be more structured and teacher-directed, a supportive teaching environment had a larger impact on strategy scores, amplifying the regional gap. This aligns with Hattie's (2012) assertion that teacher expectations and classroom climate are among the most powerful influences on student achievement. In contrast, in Non-Asia, where teaching is generally more student-centered, the benefit of a supportive teaching environment was less pronounced. This suggests that the marginal benefit of supportive environments may depend on the existing pedagogical framework in each region. Asia may benefit more from structural changes to teaching environments, while Non-Asia may need to focus on maintaining and enhancing student autonomy.

Practical Implications

The findings have significant practical implications for educators and policymakers. The study highlights the importance of region-specific reforms. In Asia, where rigid teaching structures may limit the development of positive strategies, interventions that focus on teacher support and classroom climate could significantly enhance students' strategy use and overall academic engagement. In Non-Asia, while the student-centered model is already beneficial, educators could benefit from further enhancing teacher-student interactions and providing consistent feedback. Gender-responsive teaching strategies are also crucial, especially in Asia, where girls may be under additional academic pressure. Finally, the findings suggest that SES-inclusive interventions are necessary in both regions to ensure that students from lower SES backgrounds have access to the resources and teaching environments that promote optimal mathematical strategies.

Conclusion

Using the TIMSS 2023 Grade-4 database, we find clear cross-regional differences in a validated, invariant latent index of mathematics learning strategies. On average, students in Non-Asia report more positive strategic orientations than their peers in Asia, and this contrast remains after honoring the TIMSS sampling design and accounting for clustering. These results indicate that observed differences are unlikely to be mere artifacts of measurement or sample design.

The regional gap is not uniform. It is most pronounced among girls and narrows among boys; SES is positively associated with strategy use in both regions, with steeper benefits at lower SES levels, and the teaching environment shows a positive association with strategy that is somewhat stronger in Asia. Mediation via SES or teaching environment is small but non-zero, suggesting that while composition and classroom climate matter, they do not fully account for the regional contrast. These patterns point to concrete levers including instruction emphasizing feedback and routines for classroom climate that are both tractable and scalable.

For Asia, the results highlight the payoff to explicit strategy instruction embedded in everyday lessons (e.g., structured checking of steps, targeted use of representations, and normed help-seeking), coupled with teacher feedback routines that reinforce strategic behavior. For regions outside Asia, the priority is sustaining positive orientations while addressing persistent subgroup gaps, especially for boys and students at the lower end of the socioeconomic spectrum. In both regions, school-level investments that strengthen classroom order and teacher clarity are likely to yield strategy gains net of student composition.

Limitations

Despite its contributions, this study has several limitations. First, the cross-sectional nature of the TIMSS data limits the ability to make causal inferences. Although the study identifies significant associations between region, gender, SES, and teaching environment, future research using longitudinal data would be valuable in establishing causal pathways. Second, while the study accounted for demographic variables like SES and gender, it did not include other potential contextual factors, such as teacher quality, peer influence, and parental involvement, which may also affect strategy use. Future studies should explore the interactions among these factors. Additionally, the study relied on self-reported data for some constructs, such as gender and mathematical self-concept, which could introduce social desirability bias. Although TIMSS is one of the most rigorous educational assessments, the reliance on self-report for some constructs may limit the accuracy of the measures.

Another limitation of the study is the homogeneity of the TIMSS sample. The data comes from a diverse range of countries; however, within each region, there may be significant within-region variation in educational systems that were not captured. For instance, the educational system in Japan differs substantially from that in India, yet both are categorized as Asian countries. Future studies should examine within-region differences to better understand how various educational practices within a region influence strategy use.

Finally, while the survey-weighted models used in this study are robust, they rely on cross-national comparisons that may not fully account for the complexities of educational systems across diverse socioeconomic contexts. The findings of this study would benefit from a more granular examination of specific educational interventions, especially in low-resource settings, to understand how local pedagogical strategies interact with broader regional policies.

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Declarations

Ethics approval and consent to participate

This study analyzed fully de-identified, publicly available secondary data from the TIMSS 2023 International Database; no new data were collected from human participants, and no identifying information was used. In accordance with the authors' institutional research ethics policy, analyses of de-identified public-use data are exempt from human subjects review; therefore, ethics approval and consent to participate were not required.

Consent for publication

Not applicable. The manuscript does not contain data from any identifiable individual person (including images, videos, or case details).

Not applicable

The datasets analysed during the current study are publicly available from the International Association for the Evaluation of Educational Achievement (IEA)

TIMSS 2023 repository: [https://timss2023.org/data/]. Derived analysis code and replication materials are available from the corresponding author on reasonable request.

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Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

A. E. Ma: Conceptualization, Methodology, Data Curation, Validation, Investigation, Visualization, Writing - Review & Editing. **X. Shen:** Conceptualization, Methodology, Formal Analysis, Validation, Investigation, Writing - Review & Editing. **X. Li:** Resources, Project Administration, Formal Analysis, Writing - Review & Editing. **Z. Cao:** Methodology, Data Curation, Software, Visualization, Writing - Original Draft, Writing - Review & Editing.
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