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Comparing the Association Between Teacher Collaboration and Mathematics Achievement Across Contexts: Evidence from Shanghai and England

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Abstract

Teacher collaboration is increasingly recognized as a key component of effective instruction and student learning. However, limited research has explored how this collaboration indirectly shapes student outcomes through its influence on teaching practices—especially within mathematics education and across different national contexts. This study addresses this gap by examining the mediating role of teaching practices in the relationship between teacher collaboration and student mathematics achievement, using data from the OECD (Organization for Economic Co-operation and Development) Global Teaching Insights (GTI) study. A structural equation modeling approach was employed to compare these relationships in Shanghai and England. The results indicate that teacher collaboration is positively associated with student achievement in mathematics, primarily through its indirect influence on teaching practices. Notably, the strength of this mediated relationship was greater in the England sample. These findings highlight the importance of fostering collaborative professional environments and offer cross-national insights into how collaborative practices can support student learning through enhanced instruction.

Keywords: teacher collaboration, teaching practices, student mathematics achievement, OECD Global Teaching InSights, comparative education

1. Introduction

In recent years, teacher collaboration has garnered significant attention from educators and policymakers (Kyndt et al., 2016; Vangrieken et al., 2015). Teachers who actively engage in collaboration with their peers tend to demonstrate a higher level of reflection on their teaching practices, are more motivated to explore innovative teaching strategies, and experience increased teaching self-efficacy (Bush & Grotjohann, 2020; Reeves et al., 2017; Ronfeldt et al., 2015). Both teacher collaboration and teaching practices are recognized as crucial elements in enhancing student academic achievement (King, 2014), as teachers' involvement in professional collaboration can enhance their teaching practices, thereby directly impacting student achievement (Desimone, 2009).

Despite the acknowledged significance of teacher collaboration and its influence on teaching practices, there remains a dearth of research examining such an impact in mathematics education (e.g., Doğan & Adams, 2020; Doğan & Yurtseven, 2018; Kim et al., 2017; Xie et al., 2023), particularly regarding the indirect effect of teacher collaboration on student mathematics achievement through teaching practices (Akiba & Liang, 2016; Cohen & Wiseman, 2022; Goddard et al., 2007; Ronfeldt et al., 2015). Notably, studies with an international comparative perspective are particularly deficient (Bruce et al., 2010; Chen et al., 2018; Reeves et al., 2017). Fully unpacking the relationship among teacher collaboration, teaching practices, and student mathematics achievement is essential for gaining insights into educational reforms that have already been implemented and for guiding future initiatives.

Accordingly, the purpose of this study is to examine the indirect relationship between mathematics teachers' collaboration and student mathematics achievement, with teaching practices as a mediating factor. Adopting an international comparative approach, the study draws on data from England and Shanghai to explore how this relationship manifests across distinct cultural and educational contexts. By investigating this pathway, the study aims to generate insights with practical and policy relevance for educators, researchers, and decision-makers at local, national, and global levels.

2. Literature Review

This section provides a structured synthesis of empirical studies on the relationship between teacher collaboration, teaching practices, and student mathematics achievement. It is organized into three parts: (1) teacher collaboration and teaching practices, (2) teacher collaboration and student mathematics achievement, and (3) a summary identifying gaps that inform the focus of the current study.

2.1 Teacher Collaboration and Teaching Practices

Teacher collaboration refers to professional interactions among educators—both formal and informal—centered on instructional planning, problem-solving, and reflective dialogue (Goddard et al., 2007). A growing body of research has explored how such collaboration influences teaching practices, either by focusing on specific collaborative behaviors or through latent constructs representing broader collaboration patterns. Parise and Spillane (2010), using data from 30 elementary schools in a U.S. urban district, found that collaborative discussions and seeking peer advice on mathematics instruction were significantly associated with reported instructional changes. While peer observation and feedback also showed positive associations, they were not statistically significant. Similarly, Kim et al. (2017) examined data from 1,653 Korean middle school teachers and found that informal collaboration—conversations around instructional or student issues—was positively related to student-centered teaching. However, formal meetings (subject- or non-subject-specific) did not show a significant relationship with instructional practice.

Other researchers have employed latent variables to capture teacher collaboration more holistically. Doğan and Yurtseven (2018), analyzing Teaching and Learning International Survey (TALIS) TALIS 2008 Turkish data, found that a composite measure of collaboration predicted instructional quality, even when controlling for professional development and other background factors. Likewise, Doğan and Adams (2020), using U.S. TALIS 2013 data, reported that teacher collaboration—defined by activities such as material exchange, team meetings, classroom observation, and co-planning—positively predicted effective instructional practices.

Building on this line of inquiry, Xie et al. (2023) conducted a comparative analysis using TALIS 2018 data from 2,376 teachers in England and 3,976 in Shanghai. They identified two dimensions of collaboration: "exchange and coordination" and "professional collaboration." Results showed that the exchange and coordination dimension positively correlated with instructional clarity in both settings, though it negatively predicted cognitive activation in England. In contrast, professional collaboration was positively associated with cognitive activation and assessment practices in England but showed no statistically significant effects in Shanghai.

These studies generally support the conclusion that teacher collaboration enhances teaching practices. However, the majority of this work addresses general education settings (e.g., Doğan & Adams, 2020; Kim et al., 2017; Xie et al., 2023), with relatively few focused specifically on mathematics instruction (e.g., Parise & Spillane, 2010). This underscores the need for further research examining how mathematics teacher collaboration shapes teaching practices within that specific content area.

2.2 Teacher Collaboration and Student Mathematics Achievement

Beyond teaching practices, a growing number of studies have explored the relationship between teacher collaboration and student learning outcomes, particularly in mathematics within specific country contexts. Goddard et al. (2007), using data from 47 elementary schools in a U.S. district, found that collaboration focused on curriculum planning and instructional strategies significantly predicted student achievement in mathematics and reading. Similarly, Ronfeldt et al. (2015), analyzing data from over 9,000 teachers across 336 schools, found that instructional team collaboration significantly predicted student gains in mathematics.

In Canada, Bruce et al. (2010) studied co-teaching and peer observation in two contrasting districts and found positive impacts on student mathematics achievement. Akiba and Liang (2016) reached similar conclusions using longitudinal data from 91 middle schools in Missouri, noting that collaborative networks and study groups led to significant student gains. However, their use of dichotomous measures (yes/no) may not fully capture the depth or quality of collaboration.

Contrasting findings have emerged in other studies. Mora-Ruano et al. (2019), analyzing Program for International Student Assessment (PISA) 2012 German data, reported no significant link between instruction-related collaboration and mathematics achievement. Cohen and Wiseman (2022), evaluating Washington D.C.'s LEAP program, also found minimal evidence that teacher collaboration improved student outcomes, including in mathematics.

Cross-national comparisons further complicate the picture. Reeves et al. (2017) found that only lesson-planning-related collaboration predicted mathematics achievement in the U.S., while none of the five collaboration types showed significant associations in Japan. Chen et al. (2018) also reported no positive relationship between teacher collaboration and literacy outcomes in Hong Kong, Singapore, and Taiwan. Taken together, these findings suggest that while teacher collaboration can enhance student achievement, its effectiveness may be contingent on contextual, cultural, and implementation factors.

2.3 Summary and Focus of the Current Study

The above review of current studies generally affirms the positive impact of teacher collaboration on both teaching practices and students' mathematics achievement. Nevertheless, it is worth noting that most existing studies investigating the effect of teacher collaboration on teaching practices have predominantly focused on general education, encompassing teachers across various subjects in their analyses (Doğan & Adams, 2020; Doğan & Yurtseven, 2018; Kim et al., 2017; Xie et al., 2023). Studies specifically examining this effect within mathematics education are particularly sparse (Parise & Spillane, 2010). While the positive effect of teacher collaboration on student mathematics achievement have been identified within specific countries such as the US (Akiba and Liang, 2016; Goddard et al., 2007; Ronfeldt et al., 2015) and Canada (Bruce et al., 2010), divergent findings have emerged from international comparative studies (Chen et al., 2018; Reeves et al., 2017) and studies focusing on data from particular countries including the US (Cohen & Wiseman, 2022) and Germany (Mora-Ruano et al., 2019).

Moreover, existing studies have not investigated the mediating effect of teaching practices between teacher collaboration and student mathematics achievement. As previous researchers have pointed out (Goe et al., 2008; Little et al., 2009), teaching practices directly impact students' mathematics achievement, with other factors at the teacher level, such as teacher collaboration, potentially influencing student learning outcomes through teaching practices. Hence, examining the indirect effect of teacher collaboration on student mathematics achievement becomes essential.

Accordingly, this study seeks to adopt a comparative perspective to investigate the mediating effect of teaching practices between teacher collaboration and student mathematics achievement. Shanghai and England were chosen as focal points for our comparative analysis due to their representation of Eastern and Western cultural paradigms, respectively. This approach not only enhances our understanding of the intricate dynamics between teacher collaboration, teaching practices, and student achievement but also offers valuable implications for improving educational strategies and policies in diverse cultural contexts. The specific research questions that guided the inquiry of this study are:

(1) To what extent does teacher collaboration indirectly impact student mathematics achievement, mediated by teaching practices, in Shanghai and England, respectively?

(2) What similarities and differences exist in the indirect effect of teacher collaboration on student mathematics achievement observed in Shanghai and England?

3. Method

3.1 Data Source and Samples

The current study constitutes a secondary analysis of data from Global Teaching Insights (GTI), which is an innovative, large-scale international study conducted by OECD' eight member countries and partner economies including England, Germany, and Madrid in Europe, Japan and Shanghai in East Asia, Chile, Columbia, and Mexico in Latin America (OECD, 2020a). Focusing on the important mathematics topic of quadratic equations generally covered in middle and high school curricula, the GTI study aimed at investigating the relationship between mathematics teaching and student learning gains. It also sought to delve into the interplay among contextual characteristics of teaching, teachers, and students, while also identifying any commonalities or disparities in mathematics instructional practices across the different countries/economies (Opfer, 2020).

The selection of the GTI study as our primary data source was strategic, given its collection of valuable student mathematics achievement information following teachers' unit instruction on quadratic equations. More importantly, both teachers and students in the sampled schools completed questionnaires that provided pertinent insights into mathematics teacher collaboration, teaching practices, and mathematics learning, which helps address our research inquiries.

In the Shanghai sample, data were collected from 85 teachers across 85 schools, encompassing a total of 2,613 eighth-grade students under their instruction at the time of data collection. Similarly, the England sample comprised 86 teachers from 86 schools, with a total of 2,033 students ranging from year 7 to year 11, with 71% of students in year 10 (Ingram et al., 2020). The study's student cohort had an average age of 14 years at participation (OECD, 2020a).

3.2 Variables

Figure 1 illustrates the conceptual framework guiding our study. We hypothesized that Teacher Collaboration has both a direct effect on Teaching Practices and an indirect effect on student mathematics achievement, as indicated by the variable Student Post-Test. Additionally, Teaching Practices were hypothesized to exert a direct effect on student mathematics achievement. Below is a detailed description of each variable:

Figure 1. Conceptual Framework for the Relationship Among Teacher Collaboration, Teaching Practices, and Student Mathematics Achievement

3.2.1 Teacher Collaboration

This variable represents the extent to which teachers engage in collaborative activities with their peers. In the teachers' pre-questionnaire administered before the unit instruction on quadratic equations, participants were asked how often they provide peer feedback on teaching methods, exchange or jointly develope instructional materials, deliberate about specific students' academic growth, and take part in joint professional learning initiatives. These four aspects were captured by the variables TQA18A, TQA18B, TQA18C, and TQA18D in the GTI dataset, respectively. Responses were rated on a 6-point Likert scale, ranging from 1 indicating "never" to 6 representing "once a week or more" (Praetorius et al., 2020a, 2020b). These four variables were used as indicators for the latent variable Teacher Collaboration. We theorize that increased levels of teacher collaboration positively impact Teaching Practices and, subsequently, student mathematics achievement.

3.2.2 Teaching Practices

Teaching Practices encompass the methodologies, strategies, and approaches employed by teachers in delivering instruction, specifically within the context of teaching quadratic equations. We propose that effective teaching practices directly influence student mathematics achievement. In this study, teaching practices reported by students were utilized rather than those reported by teachers, due to the comparatively higher reliability of student-reported data (Cheng et al., 2023).

In the student post-questionnaire, students were prompted to report on their teachers' teaching practices during the unit on quadratic equations. Drawing upon the Quality Instruction conceptual framework of GTI, questionnaire items were categorized into four domains as indicated in Castellano & Bell (2020) that includes Quality of Subject Matter, Discourse, Cognitive Engagement, and Assessment of and Responses to Student Understanding. As each domain is measured by multiple unidimensional items, an item parceling technique was employed to create six scales by averaging the items that measure the same concept (Bandalos & Finney, 2001; Kishton & Widaman, 1994).

The Quality of Subject Matter domain consists of two scales: Clarity Instruction and Meaning Making. Clarity Instruction is computed as the mean of items SQB08A – SQB08D, reflecting students' perceptions of their teachers' clarity of instruction during the unit on quadratic equations (OECD, 2020b). Similarly, Meaning Making is calculated as the mean of items SQB09A – SQB09D, gauging students' perception of their teacher's emphasis on meaning during the unit.

The Discourse domain is measured by the Classroom Discourse scale, derived from the mean of items SQB08I – SQB08K, capturing students' perception of their teacher's use of discourse during the unit. The Cognitive Engagement is gauged by the Cognitive Activation scale, calculated as the mean of items SQB08E – SQB08H, which assesses students' perception of their teacher's ability to elicit cognitive activation during the unit.

Lastly, the Assessment of and Responses to Student Understanding domain is assessed through two scales: Feedback and Instruction Adaptation. Feedback is determined by the mean of items SQB16A – SQB16D, measuring students' perception of the level of feedback received from their teacher. Instruction Adaptation, on the other hand, is computed as the mean of items SQB10A – SQB10E, reflecting students' perception of their teacher's adaptation of instruction to student needs during the unit (OECD, 2020b). The scales representing the four domains serve as indicators for the latent variable Teaching Practices. The questionnaire items, along with the domain and scale names, are outlined in Table 1.

Table 1. Domains, Scales, and Items for the Latent Factor Teaching Practices

Domain and Scale	Item Name and Description (The mathematics teacher …)
Quality of Subject Matter	
Clarity instruction	SQB08A-D: reviews previously taught material, outlines learning goals at the start of lessons, clarifies what students are expected to learn, and shows how new concepts connect with prior knowledge.
Meaning making	SQB09A-D: explains the rationale behind mathematical procedures, uses visual aids or real-world examples to support understanding, asks guiding questions to deepen reasoning, and compares various solution methods.
Discourse	
Classroom Discourse	SQB08I-K: encouraged students to share and explain their thinking, critically engage with their peers' reasoning, and participate in discussions that foster collective understanding.
Cognitive Engagement	
Cognitive Activation	SQB08E-H: present open-ended problems, tasks requiring transfer of knowledge, assignments that promote critical thinking, and opportunities to choose their own approaches to solving complex challenges.
Assessment of and Responses to Student Understanding	
Feedback	SQB16A-D: clarifies expectations for assessments, provides insight into student progress, highlights strengths and areas for improvement, and offers suggestions for growth.
Instructional Adaptation	SQB10A-E: tailors lessons to match student needs, adjusts explanations using alternative representations, restructures difficult content, differentiates tasks by ability, and checks for student understanding during instruction.

3.2.3 Student Mathematics Achievement

This variable represents students' performance on assessments administered following instruction on quadratic equations. It serves as a proxy for student mathematics achievement in the context of the study. We posit that both Teacher Collaboration and Teaching Practices contribute to variations in student performance on the post-test, with Teaching Practices exerting a direct effect.

In the GTI study, students' baseline mathematics knowledge was evaluated using a 30-problem pre-test administered 14 days prior to the quadratic equations lesson sequence. A 25-item post-intervention test was administered within two weeks following instruction to evaluate students' acquisition of quadratic equations concepts and skills (Praetorius et al., 2020a, 2020b). Given the post-test's direct alignment with the quadratic equations unit objectives, we operationalized mathematics achievement using students' post-test performance. To enable cross-economy comparisons among the eight participating educational systems, all scores were standardized relative to the sample mean and standard deviation, then rescaled using the Items Response Theory (IRT) model (Doan & Mihaly, 2020). Consequently, scores ranged from 100 to 300, with a mean of 200 and a standard deviation of 25 across the entire international sample.

Following the GTI study team's analytical recommendations for handling missing values, the Shanghai sample comprised 2,550 out of a total of 2,613 students and 85 teachers, while the England sample included 1,749 out of 2,033 students and 85 out of 86 teachers in the data analysis. Descriptive statistics for the variables, along with the sample sizes used in the study, are presented in Table 2 for Shanghai and Table 3 for England.

Table 2. Descriptive Statistics for the Variables from Shanghai Data

	Min	Max	Mean	S.D.	Skewness	Kurtosis
Teacher Feedback	2	6	4.50	1.25	-0.18	-1.40
Material Exchange/Development	1	6	4.88	1.39	-1.07	-0.01
Student Learning Discussion	1	6	4.41	1.42	-0.81	-0.25
Professional Learning Participation	1	6	4.24	1.35	-0.57	-0.47
Clarity Instruction	1	4	3.34	0.66	-0.89	0.41
Meaning Making	1	4	3.17	0.74	-0.63	-0.27
Classroom Discourse	1	4	3.21	0.74	-0.85	0.28
Cognitive Activation	1	4	2.80	0.76	-0.03	-0.66
Feedback	1	4	2.45	0.84	0.16	-0.77
Instruction Adaptation	1	4	3.02	0.63	-0.38	0.20
Post-Test	164.48	270.16	233.44	23.93	-0.04	-0.65

Table 3. Descriptive Statistics for the Variables from England Data

	Min	Max	Mean	S.D.	Skewness	Kurtosis
Teacher Feedback	1	6	3.76	1.38	-0.04	-0.72
Material Exchange/Development	1	6	5.02	1.20	-1.33	1.50
Student Learning Discussion	2	6	5.29	0.97	-1.31	0.90
Professional Learning Participation	1	6	4.44	1.15	-0.61	0.20
Clarity Instruction	1	4	2.84	0.70	-0.36	-0.35
Meaning Making	1	4	2.89	0.73	-0.40	-0.36
Classroom Discourse	1	4	2.70	0.80	-0.27	-0.65
Cognitive Activation	1	4	2.76	0.65	-0.15	-0.19
Feedback	1	4	2.46	0.74	-0.02	-0.58
Instruction Adaptation	1	4	2.91	0.57	-0.44	0.75
Post-Test	151.07	267.02	194.89	14.29	0.70	1.40

3.3 Data Analytic Approach

To determine if the two latent constructs, Teacher Collaboration and Teaching Practices, were adequately represented by their respective indicator variables, a confirmatory factor analysis is necessary. Then, to examine the direct effect of Teaching Practices on student mathematics achievement and the indirect effect of Teacher Collaboration on student mathematics achievement, path analysis can be employed. Since structural equation modeling (SEM) can perform both analyses simultaneously with observed and unobserved variables (Kline, 2015), we selected SEM as the major analytic approach for this study.

Initial examination of the descriptive statistics revealed that the variables do not have univariate or multivariate normality. Consequently, model parameters were estimated via Maximum Likelihood methods, with scaling adjustments applied to both fit statistics (χ^2) and standard error estimates, addressing the violations of data normality as suggested by Satorra and Bentler (1994). Utilizing the Lavaan package in R (Rosseel, 2012), we started with confirmatory factor analysis to test the measurement model comprising two latent constructs, teacher collaboration and teaching practices, along with their respective indicators. This was followed by fitting a structural regression model to address the research questions.

The latent variables were scaled in that the first factor loading from each variable was fixed at 1. Following the suggestions of Hu and Bentler (1999), we used the following criteria of model fit indices to assess model fit and interpret the results: comparative fit index (CFI) > .95; Tucker-Lewis index (TLI) > .95; Root Mean Square Error Approximation (RMSEA) < .06, and Standardized Root Mean Square Residual (SRMR) < .08. In addition, the adequacy of the measurement models was assessed using variance explained (R^2) that indicates the extent to which each indicator variable measures its underlying construct (Kline, 2004). Generally, $R^2 > .35$ is considered large, $R^2 > .15$ is moderate, and $R^2 > .02$ is small in structural equation modeling (Cohen, 1988).

4. Results

4.1 Results for the Measurement Model

The measurement model specified two factors: Teacher Collaboration and Teaching Practices. Overall, the model fit Shanghai data very well, Satorra-Bentler Scaled χ^2 (34, N= 2,550) = 187.27, $p < .001$, Satorra-Bentler CFI = .98, robust TLI = .98, RMSEA = .05 (CI: .039 ~ .051), SRMR = .03. Similarly, the measurement mode fit England data very well, Satorra-Bentler Scaled χ^2 (34, N= 1,749) = 226.20, $p < .001$, Satorra-Bentler CFI = .97, robust TLI = .96, RMSEA = .06 (CI: .05 ~ .07), SRMR = .04. All standardized factor loadings exceeded statistical significance thresholds, ranging from .61 for Cognitive Activation to .82 for Clarity Instruction in the Shanghai data, and from .44 for Teacher Feedback to .93 for Professional Learning Participation in the England data. The variances (R^2) of nearly all variables explained by their corresponding factors were large, ranging from .37 for Cognitive Activation to .67 for Clarity Instruction in the Shanghai data, and from .37 for Teacher Feedback to .87 for Professional Learning Participation in the England data, except for the item Teacher Feedback that only had 19% of variance explained by the latent factor Teacher Collaboration. Table 4 presents the measurement model's psychometric properties, including factor loadings with standard errors, variance explained estimates, and goodness-of-fit indices. The collectively strong results - excellent fit statistics, consistently significant factor loadings, and substantial variance explained - confirm the model's robust specification.

Table 4. Results of the Measurement Model with Standardized Estimates

	Factor Loading (Std. Err.)(R^2)	
	Shanghai	England
Teacher Collaboration		
Teacher Feedback	.67***(.55)(.45)	.44***(.81)(.19)
Material Exchange/Development	.76***(.42)(.58)	.64***(.59)(.41)
Student Learning Discussion	.77***(.41)(.59)	.65***(.58)(.42)
Professional Learning Participation	.62***(.62)(.38)	.93***(.13)(.87)
Teaching Practices		
Clarity Instruction	.82***(.33)(.67)	.81***(.35)(.65)
Meaning Making	.77***(.41)(.59)	.75***(.44)(.56)
Classroom Discourse	.80***(.37)(.63)	.71***(.49)(.51)
Cognitive Activation	.61***(.63)(.37)	.61***(.63)(.37)
Feedback	.66***(.57)(.43)	.68***(.54)(.46)
Instruction Adaptation	.79***(.38)(.62)	.76***(.43)(.57)
	Fit Indices	
χ^2 (df), scaled	187.27(34)***	226.20(34)***
Robust CFI	.98	.97
Robust TLI	.98	.96
Robust RMSEA	.05	.06
SRMR	.02	.04

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.2 Results for the Structural Model

To test the research assumptions, the student Post-Test scores, along with structural regression paths representing the direct and indirect relationships, were included in the structural model. Results of the structural equation modeling analysis are presented in Table 5, displaying all standardized parameter estimates (β) along with key fit indices.

Overall, the fit indices of the structural model indicated that the model fit the Shanghai data very well, with the Satorra-Bentler Scaled χ^2 (43, N= 2,550) = 250.14, $p < .001$, Satorra-Bentler CFI = .98, robust TLI = .97, RMSEA = .05 (CI: .040 ~ .051), SRMR = .03. Similarly, for the England data, the model demonstrated a good fit, with the Satorra-Bentler Scaled χ^2 (43, N= 1,749) = 373.65, $p < .001$, Satorra-Bentler CFI = .95, robust TLI = .93, robust RMSEA = .07 (CI: .063 ~ .075), and SRMR = .05.

Table 5. Results of the Structural Model with Standardized Estimates

	Shanghai	England
	Estimate (Std. Err.)	Estimate (Std.Err.)
	Factor Loadings	
Teacher Collaboration		
Teacher Feedback	.67***(.55)	.44***(.81)
Material Exchange/Development	.76***(.42)	.64***(.59)
Student Learning Discussion	.77***(.41)	.65***(.58)
Professional Learning Participation	.62***(.62)	.93***(.13)
Teaching Practices		
Clarity Instruction	.82***(.33)	.81***(.35)
Meaning Making	.77***(.42)	.75***(.44)
Classroom Discourse	.80***(.37)	.71***(.49)
Cognitive Activation	.61***(.63)	.61***(.63)
Feedback	.65***(.57)	.68***(.54)
Instruction Adaptation	.79***(.38)	.76***(.43)
	Regression Coefficient	
Teacher Collaboration	.06*(.997)	.10***(.990)
Teaching Practices	.21***(.96)	.08**(.993)
	Error Variances	
Teaching Practices	.997***	.990***
Post-Test	.96***	.993***
	Fit Indices	
χ^2 (df), scaled	250.14(43)***	373.65(43)***
Robust CFI	.98	.95
Robust TLI	.97	.93
Robust RMSEA	.05	.07
SRMR	.03	.05

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This structural model, along with the estimates of standardized regression coefficients and factor loadings, is also presented in Figure 2 for Shanghai and Figure 3 for England. All parameter estimates were statistically significant.

For the Shanghai data, Teacher Collaboration exhibited a positive and statistically significant direct effect on Teaching Practices, $\beta = .06$, $p = .010$, and it also showed a positive and statistically significant indirect effect on student Post-Test, $\beta = .008$, $p = .018$, as mediated by Teaching Practices. Additionally, Teaching Practices demonstrated a positive and statistically significant direct effect on student Post-Test, $\beta = .210$, $p < .001$. A trivial amount of variances in Teaching Practices ($R^2 = .003$) was explained by Teacher Collaboration, and a very small amount of variances in student Post-Test ($R^2 =.044$) was accounted for by Teaching Practices.

Similar results were observed in the England data. Teacher Collaboration displayed a positive and statistically significant direct effect on Teaching Practices, $\beta = .10$, $p < .001$, and it also exhibited a positive and statistically significant indirect effect on student Post-Test, $\beta = .01$, $p = .015$, as mediated by Teaching Practices. Additionally, Teaching Practices showed a positive and statistically significant direct effect on student Post-Test, $\beta = .083$, $p = .002$. A trivial amount of variances in Teaching Practices ($R^2 =.01$) was explained by Teacher Collaboration, and a very small amount of variances in student Post-Test ($R^2 =.007$) was accounted for by Teaching Practices.

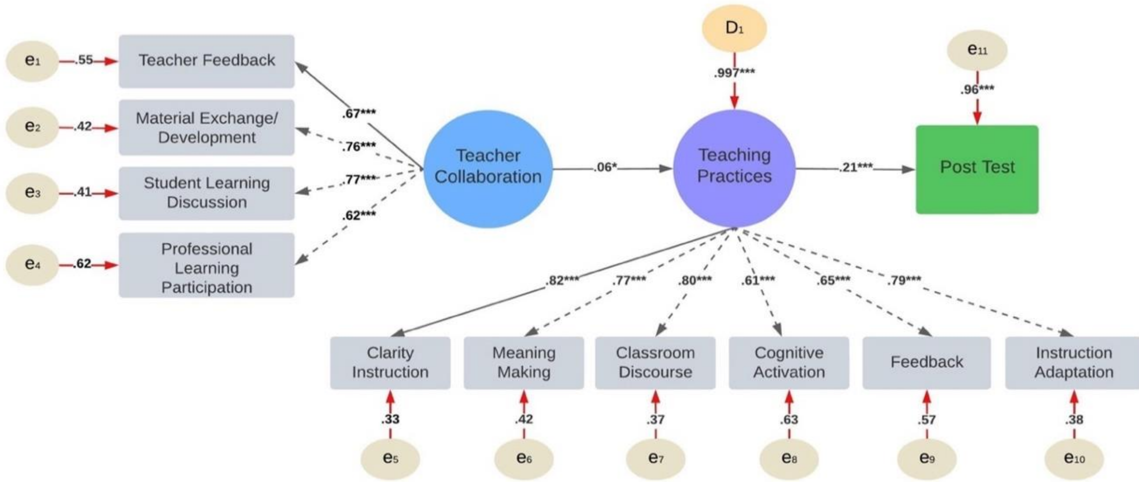

Figure 2. Results of the Structural Model Showing the Relationship Among Teacher Collaboration, Teaching Practices, and Student Post-Test with Standardized Estimates for Shanghai Data

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

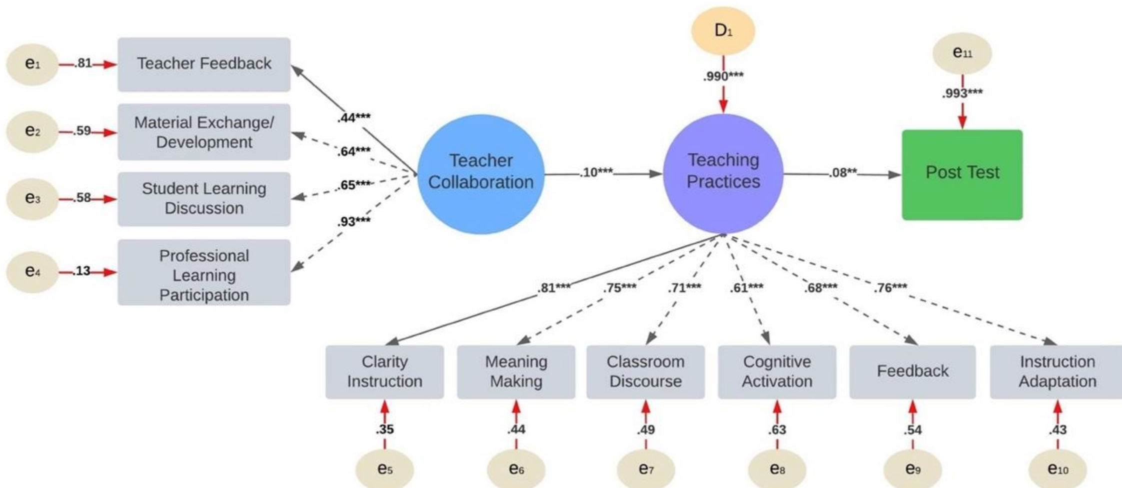

Figure 3. Results of the Structural Model Showing the Relationship Among Teacher Collaboration, Teaching Practices, and Student Post-Test with Standardized Estimates for England Data

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5. Discussion and Implications

5.1 Mathematics Teacher Collaboration and Teaching Practices

Our study contributes important empirical evidence regarding the positive and statistically significant impact of teacher collaboration on teaching practices in both Shanghai and England. Notably, we observed a stronger effect in England compared to Shanghai, though both effects appear to be relatively small in magnitude. This is particularly noteworthy given that most previous studies examining the effect of teacher collaboration on teaching practices have primarily focused on general education (Doğan & Adams, 2020; Doğan & Yurtseven, 2018; Kim et al., 2017; Xie et al., 2023) rather than mathematics education.

The findings from our study align with those of Parise and Spillane (2010), although our approach differs in that we utilized a composite scale for measuring teacher collaboration, whereas their study used individual items. Parise and Spillane (2010) identified that collaborative discussions and seeking mathematics teaching advice from peers were positive and significant predictors while peer observation and feedback showed a positive trend but did not reach a level of statistical significance. Our composite scale comprised of providing peer feedback, exchanging or developing teaching materials with colleagues, discussing the learning development of specific students, and participating in collaborative professional learning. In the Shanghai data, the item with the highest factor loading on the latent construct of Teacher Collaboration was discussing the learning development of specific students, while participating in collaborative professional learning had the lowest loading. Conversely, in the England data, participating in collaborative professional learning had the highest loading, while providing feedback to other teachers about their practice had the lowest. These findings suggest that mathematics teachers in different educational systems have distinct preferences for approaching professional collaboration. Regarding Teaching Practices, we observed that clarity instruction had the highest factor loading while cognitive activation had the lowest loading in both the Shanghai and England data. This consistency suggests that students in both Shanghai and England validly and reliably rated their teachers' instructional practices, supporting the findings of a recent study (Cheng et al., 2023) that also utilized the GTI Shanghai data to arrive at the conclusion that student evaluations of mathematics instructional methods employed by their teachers were valid and reliable.

Despite these variations in factors loading of Teacher Collaboration, we found that effect of Teacher Collaboration on Teaching Practices remains significant and positive for both Shanghai and England. Therefore, it is crucial to provide more systematic support to mathematics teachers to further enhance their collaboration. This support can include opportunities for collaborative learning and development, sharing of best practices, and creating environments conducive to open discussions about student learning and instructional strategies. Such initiatives can contribute significantly to improving teaching practices and ultimately benefit student outcomes in mathematics education.

5.2 Teacher Collaboration and Student Mathematics Achievement

Previous studies have extensively examined the direct impact of teacher collaboration on student achievement in mathematics. However, some researchers (Goe et al. 2008; Little et al., 2009) argue that among the factors influencing student achievement, only in-classroom teaching practices have a direct influence on student mathematical achievement, while other teacher-level factors, such as teacher collaboration, may affect student learning outcomes indirectly by shaping teaching practices. Our study contributes crucial empirical evidence by demonstrating that Teacher Collaboration has a positive and statistically significant indirect effect on student mathematics achievement, mediated by Teaching Practices, in both Shanghai and England. Notably, we observed again a stronger effect in England compared to Shanghai, although both effects appear to be relatively small.

Our findings seem to align with previous studies that chose to investigate the direct effect of teacher collaboration on student mathematics achievement within specific countries such as the US (Akiba and Liang, 2016; Goddard et al., 2007; Ronfeldt et al., 2015) and Canada (Bruce et al., 2010). However, our findings differ from what was found in some international comparative studies (Chen et al., 2018; Reeves et al., 2017) and studies focusing on data from certain countries like the US (Cohen & Wiseman, 2022) and Germany (Mora-Ruano et al., 2019). Their approach of investigating the direct effect of teacher collaboration on student achievement may explain the non-significant associations between teacher collaboration and student achievement. Additionally, the different grade levels these studies focused on and the different items used to indicate Teacher Collaboration might have contribute to such divergent results.

The observed differences in the impact of Teacher Collaboration on student mathematics achievement across different studies and contexts raise important considerations for educators, policymakers, and researchers. Firstly, it highlights the need for a nuanced understanding of how teacher collaboration operates within different educational systems and settings. Our findings suggest that the effectiveness of teacher collaboration in improving student outcomes is not straightforward and may vary depending on factors such as the grade levels studied, and the specific measures used to assess teacher collaboration. Moreover, the observed differences between international comparative studies and country-specific studies in the impact of teacher collaboration on student achievement highlight the complexity of educational systems and the need for context-specific approaches to improving teaching and learning. Policymakers and educational leaders should consider these nuances when designing initiatives aimed at promoting teacher collaboration and improving student outcomes.

6. Limitations and Directions for Future Research

This research has three primary limitations. First, the results are derived exclusively from GTI study datasets representing only Shanghai and England. Shanghai represents a developed urban area in China, while England represents an industrial economy. Therefore, caution should be exercised when generalizing the results to other regions or economies. A second constraint lies in the GTI study's narrow conceptual scope, examining only quadratic equations as a single representative topic within mathematics education. This narrow focus may limit the generalizability of the findings to broader mathematical concepts or instructional contexts. Third, it is important to note that the sampled teachers and students in Shanghai were primarily from the eighth grade, whereas the majority of those in the England data were from year 10. Consequently, generalizing the results to other grade levels or educational systems should be approached with caution. As a result, the interpretation of the results should be context-specific, and any implications discussed should be considered within these boundaries.

Considering the outlined limitations, we suggest that future research endeavors may replicate this study by comparing samples of teachers and students from different countries or regions, or different grade levels. This replication could help verify whether the findings regarding the indirect effect of teacher collaboration on student mathematics achievement hold consistent across different cultural and educational contexts. Additionally, future research efforts could adopt an experimental or quasi-experimental design, enabling a more rigorous investigation of the mediating effect of teaching practices between teacher collaboration and student mathematics achievement. Moreover, given that our findings highlight the role of teaching practices as a mediator between teacher collaboration and student achievement, future research could further explore the mechanisms through which teacher collaboration influences teaching practices and subsequently impacts student learning outcomes. This could involve investigating specific collaborative practices or professional development strategies that enhance teaching practices and contribute to improved student achievement.

7. Conclusion

This study examined the indirect effect of teacher collaboration on student mathematics achievement through teaching practices, using structural equation modeling and data from the OECD Global Teaching Insights (GTI) study in Shanghai and England. The analysis revealed a statistically significant indirect effect in both contexts, with the effect size notably stronger in England. These findings underscore the pivotal role of teaching practices as a mediating mechanism through which teacher collaboration can influence student outcomes. By anchoring the results in robust statistical evidence, this study contributes to a more nuanced understanding of how collaborative professional interactions among teachers can translate into improved instructional quality and, ultimately, student achievement in mathematics. Future research should extend this line of inquiry by investigating additional mediators or moderators that may account for cross-cultural differences and further refine our understanding of effective collaboration within diverse educational systems.

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Authors contributions

Qiang Cheng conceptualized the study and drafted the manuscript. Tom Brady contributed to part of the literature review section. All authors approved the manuscript.

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The data that support the findings of this study are available at
https://www.oecd.org/en/about/projects/global-teaching-insights.html#technical

Data sharing statement

No additional data are available.

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