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The Influence of Subject-Specific Teacher Professional Development on Student Achievement In Secondary Schools In China

Cai Jinru, Nurliza Haslin Muslim

ALFA University College, Malaysia

Abstract

This study investigates the influence of subject-specific teacher professional development (SS-TPD) on student achievement in secondary schools across China. Drawing on a quantitative design, data were collected from 376 teachers through structured questionnaires and matched with student performance records. The study examined both direct and indirect effects of SS-TPD on student outcomes, mediated by teacher pedagogical practices (TPP). Structural Equation Modeling (SEM) using PLS-SEM techniques confirmed strong and significant relationships among the constructs. Findings revealed that SS-TPD had a substantial positive effect on TPP ($\beta = 0.805$, $p < 0.001$) and student achievement ($\beta = 0.374$, $p < 0.001$), with TPP also exerting a positive influence on achievement ($\beta = 0.342$, $p < 0.001$). Moreover, TPP partially mediated the relationship between SS-TPD and achievement, underscoring the central role of effective pedagogy in translating teacher learning into student success. The study highlights the importance of sustained, collaborative, and content-focused professional development within China's exam-driven educational context. Implications are drawn for theory, practice, and policy, emphasizing the need for systemic support and equitable access to SS-TPD, particularly in under-resourced regions.

Keywords : Subject-Specific Teacher Professional Development, Teacher Pedagogical Practices (TPP), Student Achievement, Secondary Education in China, Educational Policy and Reform

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1. Introduction

Education remains a cornerstone of national development, with teacher quality recognized as a decisive factor in student achievement. Teacher professional development (TPD) has thus become central to educational reform, though its impact varies depending on focus and design. Increasingly, researchers and policymakers advocate for subject-specific teacher professional development (SS-TPD) as a more effective approach to enhancing instructional practices and learning outcomes compared to general training (Ajani & Govender, 2025; Desimone & Garet,

2015; Kang et al., 2013; Milner & Scholkmann, 2023). SS-TPD, which integrates content mastery with pedagogical strategies—often framed as pedagogical content knowledge (Abir ROUABHIA, 2024; Gudmundsdottir & Shulman, 1987; Reyes et al., 2021) has been empirically linked to higher instructional quality and improved student performance. For example, mathematics-focused training has been shown to strengthen teaching effectiveness and boost student test scores (Hill et al., 2005). International evidence from the U.S. and U.K. similarly highlights that subject-specific training aligned with curriculum goals improves academic outcomes (Darling-Hammond et al., 2017). In China, educational reforms prioritize teacher quality, particularly due to the central role of high-stakes examinations such as the Zhongkao and Gaokao (MOE, 2019). Yet, many professional development initiatives remain generic, leading to inconsistent results, especially in rural or under-resourced areas (Amin, 2024; Derman & Jaeger, 2018; Wang et al., 2020). Evidence suggests that SS-TPD fosters inquiry-based pedagogy and greater student engagement (Chen et al., 2021; Wang & Xu, 2024), but disparities in access persist between urban and rural schools (Li et al., 2025; Li et al., 2021). Challenges such as limited funding, trainer shortages, rigid schedules, and weak policy support hinder the broader adoption of SS-TPD (Warwick et al., 2017; Zhang & Liu, 2014). Moreover, most existing studies emphasize teacher perceptions, with limited research directly examining student-level academic outcomes. This study therefore addresses a critical gap by investigating the impact of SS-TPD on student achievement in secondary schools across China. By focusing on subject-specific practices and gathering evidence from both teachers and students, it aims to identify effective strategies, promote equitable access, and provide actionable insights for policymakers, educators, and researchers. Ultimately, SS-TPD, with its integration of content and pedagogy, emerges as a promising pathway for improving student learning in China's high-stakes educational environment.

In recent years, China has invested heavily in enhancing teacher quality, yet much of this professional development remains general and insufficiently aligned with subject-specific instructional needs (Jing, 2025; Liao et al., 2024). Subject-specific teacher professional development (SS-TPD), which emphasizes discipline-based pedagogy and knowledge, is unevenly implemented across secondary schools, raising concerns about its effectiveness in improving student learning (Crisan & Hobbs, 2019; Kyriakides et al., 2024; Zhang & Liu, 2014). Despite policy attention, empirical research mapping the availability, accessibility, and nature of SS-TPD in China is limited (Li et al., 2023; Wang et al., 2025). Research consistently shows that SS-TPD

yields stronger instructional improvements than general training, as it equips teachers with content-specific strategies and deeper insights into student learning within disciplines (Desimone et al., 2025; Desimone & Hill, 2017; Heller et al., 2012; Lee & Vongkulluksn, 2023). International evidence further suggests that students benefit academically when taught by teachers engaged in high-quality SS-TPD (Darling-Hammond et al., 2017; Darling-Hammond et al., 2024; Niemi, 2011; Schleicher, 2012). However, evidence within China, particularly in high-stakes subjects such as mathematics, science, and Chinese, remains scarce.

2. Literature Review

2.1 Introduction

Teacher professional development (TPD) is widely acknowledged as a critical driver of educational reform and improved student outcomes (Darling-Hammond et al., 2017; Kilag & Sasan, 2023; Sims et al., 2025). It encompasses both formal and informal learning experiences—including workshops, mentoring, collaborative learning, and coursework—designed to enhance teachers' professional knowledge, skills, and practices throughout their careers (Avalos, 2011; DeSimone, 2016; Shin & Kim, 2021). While definitions vary, most scholars agree that TPD is a continuous, multidimensional process that impacts not only teachers' knowledge but also their beliefs, attitudes, and instructional practices (Guskey, 2002b; Vermunt, 2014).

The field has evolved from traditional, top-down delivery models to more collaborative, reflective, and teacher-driven approaches that emphasize professional identity and agency (Avalos, 2011). (DeSimone, 2016) identifies five key features of high-quality TPD: content focus, active learning, coherence with school and curriculum goals, duration over time, and collective participation within professional communities (Copeland, 2018; Gaye, 2015; Green, 2023; Lindvall & Ryve, 2019; Patterson, 2012). These features remain central benchmarks for evaluating professional development initiatives. TPD further spans three interrelated domains: cognitive (subject knowledge and pedagogical strategies), behavioral (classroom application and instructional change), and affective (attitudes, motivation, and self-efficacy) (Avalos, 2011; Gallucci, 2008). Collaborative models such as professional learning communities (PLCs) strengthen teacher growth by fostering reflection, innovation, and shared responsibility (Lieberman & Miller, 2011; Vescio et al., 2008). Leadership and school culture also shape professional learning through resource provision, policy alignment, and organizational support (Louis & Leithwood, 2021; Opfer & Pedder, 2011). Additionally, technology has expanded the reach of TPD, enabling flexible and

scalable professional learning through digital platforms, though requiring careful design for effectiveness (Goyal, 2023; Vetrivel et al., 2024).

2.2 Subject-Specific vs. General Professional Development

Within this broader framework, TPD can be divided into subject-specific and general approaches. Subject-specific professional development (SS-TPD) is rooted in deepening disciplinary knowledge and pedagogical content knowledge (PCK) the ability to represent subject matter and address misconceptions. For example, mathematics-focused training enhances conceptual understanding and teaching strategies for problem solving (Garet et al., 2001). Evidence suggests that SS-TPD has a stronger impact on student achievement since it targets the curriculum and pedagogy directly linked to learning outcomes (Yoon et al., 2007). Moreover, SS-TPD often involves collaboration among subject teachers, enabling collective problem-solving and shared practice. By contrast, general professional development addresses broad pedagogical skills, classroom management, assessment techniques, and technology integration applicable across subjects. While valuable for overall teaching competence, its effect on subject-specific student achievement tends to be less immediate (Hill et al., 2013). In China's highly subject-oriented secondary school system, this distinction is particularly important. The Ministry of Education has emphasized SS-TPD to improve instructional quality and mitigate regional disparities in student performance. Nevertheless, scholars argue that the integration of both approaches, merging general pedagogical skills with subject-specific expertise—offers the most comprehensive professional growth (Avalos, 2011; de Clercq & Shalem, 1994; Guskey, 2002a; Kyriakides et al., 2024). Yet, limited empirical evidence exists on how these models translate into measurable student achievement in China, highlighting a key gap that this study seeks to address.

2.3 Theoretical Framework

Understanding the influence of subject-specific teacher professional development (SS-TPD) on student achievement requires grounding in key educational theories. This study draws on Adult Learning Theory (Andragogy), Constructivist Learning Theory, and Teacher Change Models, particularly Guskey's model, to explain how teachers learn, adapt practices, and impact student outcomes. Adult Learning Theory (Andragogy) emphasizes that adults learn best when learning is self-directed, experiential, relevant, and problem-centered (Egan, 2020; Knowles, 1980; Knowles et al., 2014). Applied to TPD, this framework suggests that professional learning must connect to teachers' classroom realities, recognize prior experiences, and foster autonomy. In SS-TPD,

aligning content with curricular needs increases motivation, engagement, and likelihood of practice change (Avalos, 2011). Constructivist Learning Theory, rooted in (Vygotsky, 1978), positions teachers as active knowledge constructors through collaboration, dialogue, and reflection (Suhendi, 2018; Zajda & Zajda, 2021). The Zone of Proximal Development (ZPD) underscores learning as most effective when scaffolded just beyond current competence. SS-TPD framed by constructivism promotes content-specific exploration, often via professional learning communities or lesson study groups, fostering both individual and institutional growth (Gray, 2018; Kessy, 2019; Vescio et al., 2008). Guskey's Model of Teacher Change (Guskey, 1999, 2000, 2002a) (1999, 2000, 2002a) provides a sequential framework, arguing that belief change follows evidence of student improvement. His five evaluation levels reactions, learning, organizational support, classroom application, and student outcomes ensure PD effectiveness is measured through both teacher practice and student achievement. In SS-TPD, teachers are more likely to sustain new strategies when linked to observable student success. Together, these three theories create a holistic framework: andragogy explains adult learning conditions, constructivism details knowledge internalization, and Guskey's model demonstrates the translation of learning into classroom change and student outcomes. This integrated approach provides a comprehensive lens for designing, implementing, and evaluating SS-TPD in ways that are effective, sustainable, and contextually relevant.

2.4 Empirical Review and Effectiveness Factors

2.4.1 International Studies on TPD and Student Achievement

Global research consistently demonstrates that teacher professional development (TPD), particularly when subject-specific, positively influences student learning outcomes. (Yoon et al., 2007) reviewed over 1,300 studies and concluded that well-designed programs significantly raise achievement in mathematics and science. U.S. benchmarks emphasize content focus, active learning, coherence, sustained duration, and collective participation (DeSimone, 2016; Garet et al., 2001). Similar trends are found globally: OECD's TALIS survey highlighted that ongoing TPD correlates with higher instructional confidence and improved student results on international assessments (OECD, 2019). Studies in Australia and Canada likewise stress curriculum-linked, job-embedded, and collaborative learning as key to improving teaching quality and student achievement (Campbell, 2017; Ingvarson et al., 2005).

2.4.2 TPD Research in China

China has prioritized TPD through national reforms such as the National Teacher Training Program (NTTP), launched in 2010, which emphasizes subject-specific training and ICT integration (MOE, 2019; Zhou et al., 2023). Studies confirm that content-focused TPD enhances teacher efficacy and instructional quality, though access disparities persist between urban and rural schools (Ling et al., 2020; Song & Li, 2024). Recent research underscores the importance of reflective practice and context-sensitive training (N. Li et al., 2022; R. Li et al., 2022; Liu et al., 2025), with evidence showing SS-TPD significantly boosts student learning, particularly in STEM (Liu et al., 2025).

2.4.3 Impact of Subject-Specific Training on Practice

Subject-specific TPD (SS-TPD) has been shown to strengthen pedagogical content knowledge and foster student-centered practices such as inquiry-based learning (Borko et al., 2010; Wilson, 2011). In mathematics, greater content knowledge enhances teachers' ability to address misconceptions and improve problem-solving instruction (Hill et al., 2005; Schons et al., 2023). Similar effects are reported in science and language teaching, where targeted training improved engagement, differentiated instruction, and achievement (Herner-Patnode & Lee, 2021; Lu et al., 2025; Richards & Farrell, 2005; Yang et al., 2024). Evidence consistently shows that SS-TPD outperforms general training in relevance, engagement, pedagogical improvement, and student outcomes.

2.4.4 Factors Influencing Effectiveness of TPD

The success of TPD is shaped by design and context. Duration is critical: long-term, sustained programs produce deeper learning and practice change (Desimone, 2009; Yoon et al., 2007). Content focus and relevance ensure alignment with teachers' curriculum and classroom needs, significantly improving instructional quality and student outcomes (Borko et al., 2010; Edwards-Fapohunda, 2024; Garet et al., 2001; Hill et al., 2005). Equally vital is school-level support and collaboration. Leadership that allocates resources, prioritizes professional learning, and fosters a supportive culture enhances implementation and sustainability (Darling-Hammond, 2017; Darling-Hammond, 2023; Fullan, 2007; Goodwin et al., 2017). Peer collaboration, especially through Professional Learning Communities (PLCs), enables teachers to co-develop lessons, analyze student data, and share strategies, leading to collective responsibility and lasting

instructional change (Vescio et al., 2008), Table 1 summarizes the Teacher Professional Development (TPD) and Student Achievement studies.

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Table 1.Teacher Professional Development (TPD) and Student Achievement

Author(s)/Year	Context	Focus	Findings	Relevance to Study
Yoon et al. (2007)	U.S., Meta-analysis (1,300+ studies)	General & Subject-Specific TPD in Math/Science	Content-focused, well-designed TPD significantly improved student achievement	Establishes strong empirical link between SS-TPD and outcomes
Garet et al. (2001)	U.S. (large-scale study)	TPD design (content, active learning, duration)	Programs with content focus + active learning improved teacher practices, benefiting students	Supports use of Desimone's five TPD features
Desimone (2009)	Theoretical framework	Five core features of TPD	Content focus, active learning, coherence, duration, and collective participation define high-quality TPD	Provides evaluation framework for this study
OECD (2019, TALIS Survey)	Europe/International	Continuous TPD and teacher confidence	Teachers in sustained, subject-linked PD were more effective and correlated with higher student PISA scores	Highlights global evidence of TPD effectiveness
Ingvarson et al. (2005)	Australia	TPD linked to curriculum/practice	Curriculum-linked PD improved teaching strategies and student outcomes	Reinforces need for practice-embedded PD
Campbell (2017)	Canada	Job-embedded collaborative PD	Sustained collaborative learning raised teacher quality and achievement	Supports role of collaboration and PLCs
Wang & Paine (2003)	China (secondary schools)	PD emphasizing content & pedagogy	Improved teacher efficacy and classroom practices	Demonstrates effectiveness of SS-TPD in Chinese context
Chen (2010)	China (urban vs. rural)	Access to PD	Urban teachers had more access; rural teachers disadvantaged	Highlights equity issues in China
Liu & Li (2020); Liu et al. (2025)	China (STEM)	Reflective practice & SS-TPD	Context-sensitive SS-TPD improved teacher practice and student outcomes	Provides recent Chinese empirical evidence
Zhou et al. (2023)	China (NTTP evaluation)	National Teacher Training Program	Subject-specific + ICT-focused PD improved teacher competence & STEM learning	Shows government-backed SS-TPD success
Borko et al. (2010)	U.S. (Math)	SS-TPD workshops	Improved teacher content knowledge, confidence, and inquiry-based teaching	Supports SS-TPD's impact on pedagogy

Wilson (2011)	U.S. (Science)	Content-focused PD	Promoted inquiry-oriented teaching; improved student achievement	Evidence for science SS-TPD relevance
Richards & Farrell (2005)	Language teaching	SS-TPD in English	Enhanced differentiated instruction, communicative teaching, student engagement	Extends SS-TPD benefits beyond STEM
Yang et al. (2024)	China (Physics teachers)	SS-TPD in science	Increased interactive methods → improved engagement and achievement	Demonstrates recent Chinese SS-TPD success
Lu et al. (2025)	China (PLCs in secondary)	SS-TPD collaboration	Subject-focused PLCs improved strategies, assessments, and student outcomes	Shows collective PD impact in China
Hill, Rowan, & Ball (2005)	U.S. (Math)	Math Knowledge for Teaching (MKT)	Strong link between MKT and student performance	Validates subject knowledge as core to SS-TPD
Schons et al. (2023)	International (Math)	SS-TPD and misconceptions	Teachers with higher MKT better diagnosed misconceptions, improving learning	Reinforces role of subject-specific expertise

2.5. Conceptual Framework

The conceptual framework of this study examines the influence of Subject-Specific Teacher Professional Development (SS-TPD) on student achievement in Chinese secondary schools, with teacher pedagogical practices serving as the mediating variable. Grounded in (Desimone, 2009) professional development model and supported by empirical evidence, the framework illustrates how content-focused and sustained teacher learning translates into improved classroom practices and, ultimately, better student outcomes.

2.5.1 Variables and Constructs

The independent variable (IV) in this study is Subject-Specific Teacher Professional Development (SS-TPD), which refers to targeted professional learning activities designed to enhance teachers' disciplinary knowledge and pedagogical strategies in areas such as mathematics, science, and language. Drawing on (Desimone, 2009) framework, SS-TPD is characterized by content focus, active learning, coherence, sustained duration, and collaborative participation. These dimensions ensure that professional learning is directly relevant to the instructional demands of the classroom, equipping teachers with the expertise necessary to address subject-specific challenges and improve their instructional effectiveness. The mediating variable (MV) is Teacher Pedagogical Practices (TPP), which encompass the instructional strategies, teaching methods, and student engagement

practices employed in classroom settings. Existing scholarship suggests that SS-TPD exerts its influence on student outcomes primarily through changes in pedagogy, fostering more effective, student-centered, and inquiry-driven approaches to teaching (Avalos, 2011). As teachers adopt innovative methods and refine their classroom practices, they create learning environments that promote deeper understanding, critical thinking, and active participation among students. Finally, the dependent variable (DV) is Student Achievement (SA), representing measurable academic outcomes such as grades, standardized test scores, and curriculum-based assessments. These outcomes serve as indicators of the ultimate impact of improved teaching quality on student learning. By positioning SS-TPD as the independent variable, TPP as the mediating mechanism, and SA as the dependent variable, the framework underscores the interdependent pathways through which professional development enhances teacher capacity and, in turn, elevates student performance, Figure 1.

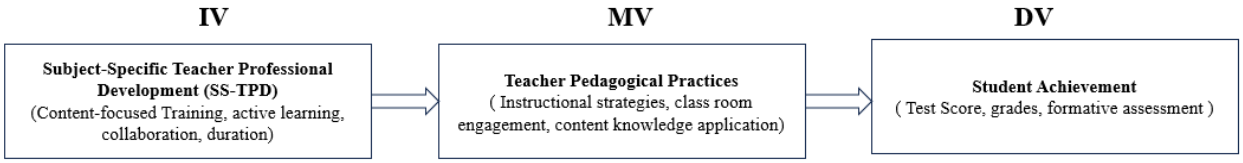

Figure 1: Conceptual Framework of the Influence of Subject-Specific Teacher Professional Development

2.5.2 Relationships among Variables

The framework proposes a mediated causal pathway in which subject-specific teacher professional development (SS-TPD) enhances teachers' subject knowledge and pedagogical skills, thereby reshaping instructional practices toward more innovative and student-centered approaches. These improvements in pedagogy, in turn, lead to measurable gains in student achievement, positioning pedagogy as the central mechanism through which teacher development translates into improved learning outcomes. Furthermore, the framework acknowledges a feedback loop, whereby gains in student achievement reinforce teachers' motivation to engage in further professional development, ultimately sustaining a cycle of continuous instructional growth and academic success.

2.5.3 Conceptual Model

the model positions SS-TPD as the primary input, teacher pedagogical practices as the mechanism of change, and student achievement as the ultimate outcome. By focusing on this mediated relationship, the framework provides a process-oriented understanding of how targeted professional development initiatives can improve secondary education quality in China.

3. Research Methodology

This study employed a quantitative, cross-sectional survey design to examine the relationship between subject-specific teacher professional development (SS-TPD) and student achievement in Chinese secondary schools. Quantitative methods were chosen to provide measurable, generalizable findings, drawing data from both teachers and their students.

3.1 Research Design, Population, and Sampling

This study adopted a cross-sectional research design, capturing data at a single point in time by integrating teacher questionnaire responses with student performance records. The target population consisted of secondary school teachers specializing in core subjects mathematics, science, and Chinese language along with their respective students. To enhance representativeness, a stratified random sampling strategy was applied, ensuring coverage across provinces, school types, and urban–rural contexts. The final sample size was determined through power analysis, thereby guaranteeing sufficient statistical power to detect significant effects with reliability. Data collection relied on three primary instruments. First, structured questionnaires were administered to measure teachers' participation in professional development (PD), their perceptions of program quality, instructional changes, and perceived effects on student outcomes. These items were adapted from established frameworks and previous literature, with the instrument demonstrating strong internal consistency (Cronbach's $\alpha = 0.87$). Second, academic performance records, including standardized examinations, subject-specific assessments, and course grades, provided objective indicators of student achievement, anonymized to ensure confidentiality. Third, PD program documentation—comprising curricula, attendance logs, and trainer credentials, was collected to validate program quality and contextualize the reported experiences. Together, these instruments enabled a comprehensive and triangulated examination of the relationship between teacher professional development, pedagogical practices, and student achievement.

3.2 Validity and Reliability

Instrument validity was established through expert review, pilot testing (n=30), exploratory factor analysis, and correlations with student performance data. Reliability testing showed strong internal consistency ($\alpha > 0.80$), test-retest stability (ICC = 0.85), and inter-rater agreement (92% for coding open responses).

3.3 Data Collection Procedures

Permissions were secured from education bureaus, schools, and the university IRB. Questionnaires were distributed in both paper and online formats to maximize participation (response rate = 78%). Student achievement data were anonymized and linked to teachers. Rigorous data management included double-entry checks, encryption, and statistical screening for errors.

3.4 Data Analysis Techniques

The analysis employed a combination of descriptive and inferential statistical techniques using SPSS and Stata. Preliminary procedures involved data cleaning, assessment of normality, and recalculation of reliability scores to ensure the integrity and consistency of the dataset. Inferential

analyses were then conducted to examine the hypothesized relationships. Correlation analysis was used to explore associations between teacher professional development (PD) and student outcomes, while multiple regression models were applied to assess the predictive effects of PD on achievement, controlling for covariates such as teacher experience, school type, and socio-economic status (SES). Analysis of variance (ANOVA) further allowed for comparison of student achievement across varying levels of PD participation. Additionally, Structural Equation Modeling (SEM) was considered as an optional advanced technique to test the full causal pathways linking PD quality, teacher self-efficacy, instructional practices, and student achievement. To enhance the robustness and validity of findings, triangulation was employed through the integration of multiple data sources, including teacher questionnaires, student academic records, and professional development program documentation.

3.5 Ethical Considerations

The study adhered to strict ethical standards: informed consent, confidentiality, anonymization of student data, voluntary participation, and IRB approval. Data were stored securely and reported only in aggregated form to protect individual identities.

4. Data Analysis and Results

This chapter presents the empirical findings examining the interrelationships among Teacher Professional Development (TPD), Teacher Pedagogical Practices (TPP), and Student Achievement (SA). The analysis was guided by four key objectives: to determine the effect of TPD on TPP, to examine the influence of TPP on SA, to assess the direct impact of TPD on SA, and to test whether TPP mediates the relationship between TPD and SA. Correspondingly, four hypotheses (H1–H4) were formulated and tested. The study employed Partial Least Squares Structural Equation Modeling (PLS-SEM) to evaluate both direct and indirect pathways, with bootstrapping applied to determine significance. Model adequacy was assessed through coefficients of determination (R^2), effect sizes (f^2), and predictive relevance (Q^2), ensuring that the structural framework was both statistically robust and theoretically grounded. Prior to structural estimation, rigorous data preparation was undertaken to ensure validity and reliability. The dataset, collected via structured online questionnaires, underwent systematic coding, editing, and preparation for analysis in SPSS and SmartPLS. Variables were assigned standardized codes: TPD dimensions included content focus, active learning, collaboration, and duration; TPP encompassed instructional strategies, classroom engagement, and content application; while SA included standardized test scores, course achievements, and formative assessments. This structured coding ensured consistency and alignment with the SEM model, enhancing analytical transparency and

replicability (Creswell & Creswell, 2017). Preliminary diagnostic checks were performed to verify dataset integrity and adherence to SEM assumptions. Missing data, a common concern in quantitative research, were eliminated through the use of mandatory response fields in the online questionnaire, resulting in a dataset with no incomplete entries. This methodological strength avoided the need for imputation or deletion techniques, which could otherwise compromise sample size and statistical power (Creswell & Creswell, 2017). Outlier detection was carried out using the Mahalanobis D^2 statistic, which measures multivariate distance to identify extreme cases. Six responses exceeded the chi-square threshold ($p \leq 0.001$) and were consequently removed to improve the reliability of parameter estimates and model fit , Table 2. One borderline case ($p = 0.002$) was retained, consistent with the cautionary guidance of (Hair, 2014). The refined dataset thus consisted of 376 valid cases, offering sufficient statistical power for SEM testing while ensuring internal validity (Tabachnick & Fidell, 2019).

Through these preparatory and diagnostic procedures, the dataset was confirmed as robust and suitable for subsequent model testing. The systematic approach to data handling safeguarded against biases, strengthened internal validity, and ensured that the subsequent analysis of TPD, TPP, and SA relationships would yield reliable, generalizable findings.

Table 2. Multivariate Outliers Detected Using Mahalanobis D^2

No.	Case ID	Mahalanobis D^2	*p*-value
1	45	25.33789	<0.001
2	189	24.76521	<0.001
3	87	24.11074	<0.001
4	167	23.59783	<0.001
5	22	23.12946	<0.001
6	268	22.69123	<0.001
7	33	21.9155	>0.001

4.1 Assessing Normality

An essential step in preparing the dataset for structural equation modeling (SEM) is evaluating its distributional properties. While variance-based SEM approaches, such as Partial Least Squares SEM (PLS-SEM), do not strictly assume multivariate normality, assessing univariate normality remains important to ensure the robustness of parameter estimation and the appropriateness of related parametric procedures (Hair, 2014).

In this study, skewness and kurtosis statistics were employed to examine the distribution of all constructs. Skewness measures the degree of asymmetry in a distribution, whereas kurtosis indicates the heaviness of its tails compared to a normal curve. Following established thresholds, values within ±2 for both indices were considered acceptable for parametric analysis (Hair, 2014). The results, summarized in Table 3, confirmed that all constructs exhibited acceptable distributional characteristics. Teacher Professional Development (TPD) dimensions, including content-focused training (TPDa), active learning (TPDb), collaboration (TPDc), and duration (TPDd), displayed negative skewness values ranging from –1.064 to –1.615, with kurtosis below 2. These findings suggest a modest clustering of responses toward higher agreement with professional development indicators. Similarly, Teacher Pedagogical Practices (TPP), represented by instructional strategies (TPPa), classroom engagement (TPPb), and content knowledge application (TPPc), showed moderate negative skewness (–0.996 to –1.565) and acceptable kurtosis, indicating consistently high self-reported teaching practices.

Student Achievement (SA), measured through standardized test performance (SAa), course achievement (SAb), and formative assessments (SAc), also demonstrated acceptable values, with skewness ranging from –1.192 to –1.956 and kurtosis between 1.552 and 1.716. These results reflect relatively high levels of student performance without extreme deviations from normality.

Table 3. Skewness and Kurtosis for All Constructs

Constructs	Sub-constructs	Code	Skewness	Kurtosis
Teacher Professional Development	Content-focused training	TPDa	–1.615	1.542
	Active learning	TPDb	–1.455	1.727
	Collaboration	TPDc	–1.064	0.734
	Duration	TPDd	–1.453	0.953
Teacher Pedagogical Practices	Instructional strategies	TPPa	–1.338	1.892
	Classroom engagement	TPPb	–0.996	0.495
	Content knowledge application	TPPc	–1.565	1.746
Student Achievement	Standardized Test Performance	SAa	–1.956	1.645
	Course Achievement	SAb	–1.192	1.552
	Formative assessments	SAc	–1.398	1.716

4.2 Descriptive Analysis of Respondents' Demographics

To contextualize the empirical findings, this study analyzed the demographic characteristics of the 376 participating secondary school teachers. The diversity of the sample enhances both the robustness and generalizability of results regarding Teacher Professional Development (TPD), Teacher Pedagogical Practices (TPP), and Student Achievement (SA). The gender distribution was relatively balanced, with 44.7% male (n = 168) and 55.3% female (n = 208) respondents, allowing

for meaningful gender-based comparisons where necessary. Age distribution revealed that the majority of participants were in mid-career stages, with 38.8% (n = 146) aged 30–39 and 31.9% (n = 120) aged 40–49. Younger teachers (20–29 years) accounted for 13.8% (n = 52), while 15.4% (n = 58) were aged 50 and above. This distribution indicates representation across early, middle, and late teaching careers. In terms of qualifications, over half of the respondents (52.7%) held a Bachelor's degree, 40.4% held a Master's degree, and 3.7% had completed doctoral studies. A smaller proportion (3.2%) reported other educational backgrounds. These results highlight a predominantly well-qualified teaching workforce, relevant for examining the effects of professional development and pedagogical practice. Professional experience was also varied, with 14.9% of teachers reporting 1–5 years of teaching, 32.4% with 6–10 years, 31.4% with 11–15 years, and 21.3% with more than 16 years of service. This balance between novice, mid-career, and veteran teachers ensures that perspectives across different career stages are captured, further strengthening the validity of the study's conclusions, see Table 4.

Table 4. Demographic Summary of Respondents (N = 376)

Variable	Category	Frequency (n)	Percentage (%)
Age	20–29	52	13.8%
	30–39	146	38.8%
	40–49	120	31.9%
	50+	58	15.4%
Gender	Male	168	44.7%
	Female	208	55.3%
Highest Educational Qualification	Bachelor's Degree	198	52.7%
	Master's Degree	152	40.4%
	Doctorate	14	3.7%
	Other	12	3.2%
Years of Teaching Experience	1–5 years	56	14.9%
	6–10 years	122	32.4%
	11–15 years	118	31.4%
	16+ years	80	21.3%

4.3 Assessment of the Measurement Model

Before testing the structural model, it is essential to establish the reliability and validity of the measurement model, as this ensures the accuracy and credibility of statistical inferences (Hair, 2014). The measurement model assessment in this study focused on two key aspects: reliability, which evaluates the consistency of construct measurement, and validity, which examines whether constructs are both adequately measured and distinct. Reliability was assessed through standardized indicator loadings and composite reliability, while validity was evaluated via

convergent and discriminant validity measures. As illustrated in Figure 2, the evaluation process included tests of standardized item loadings, average variance extracted (AVE), cross-loadings, the Fornell-Larcker criterion (square root of AVE), and the heterotrait-monotrait ratio of correlations (HTMT).

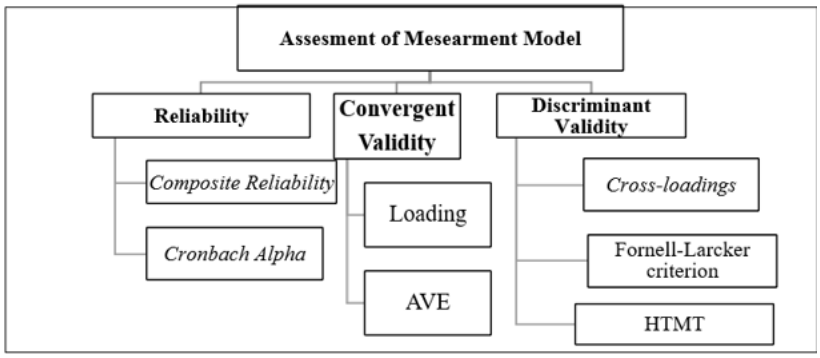

Figure 2: Assessment of the Measured Model Outline

The measurement model consisted of 44 observed items measuring seven reflective constructs, as shown in Figure 3. Results demonstrated strong convergent validity, with all AVE values exceeding the recommended threshold of 0.50, indicating that each construct explained sufficient variance in its respective indicators. This confirmed that items within each construct were highly correlated.

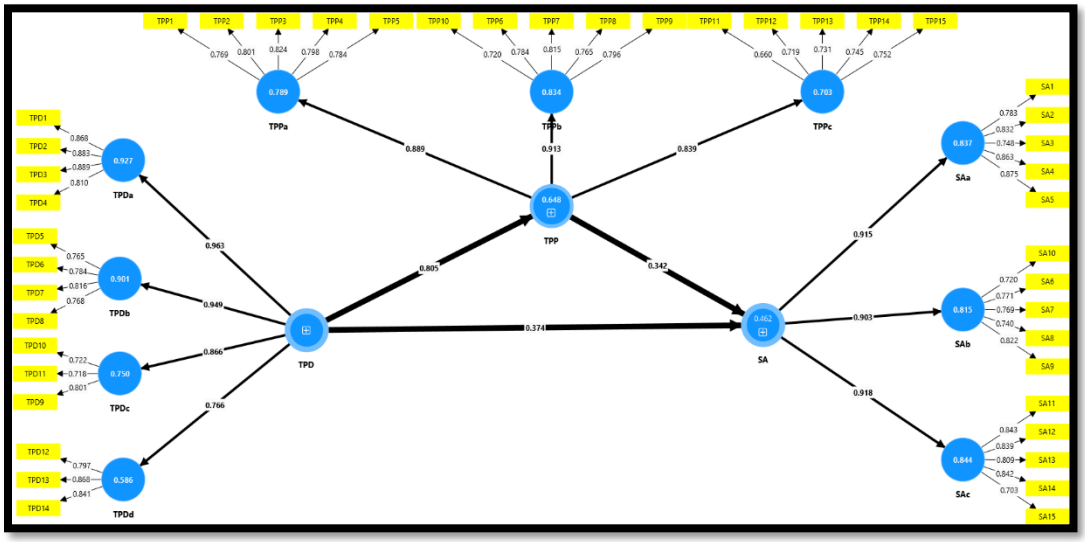

Figure 3: The Measurement Model

Discriminant validity was also well established. Cross-loading analyses, Fornell-Larcker criteria, and HTMT ratios all confirmed that constructs were statistically distinct from one another. Taken together, these findings suggest that the model possesses strong psychometric properties. The combination of high standardized loadings, robust composite reliability, and confirmed convergent and discriminant validity demonstrate that the measurement model is well established and suitable for subsequent hypothesis testing and structural model analysis.

4.4 Assessment of the Measurement Model

Consistent with best practice in variance-based SEM, the measurement model was evaluated for reliability and validity prior to estimating the structural relations, ensuring that subsequent inferences are accurate and credible (Hair, 2014). Reliability examines whether indicators consistently measure their latent constructs (via standardized loadings, Cronbach's α, and Composite Reliability, CR), while validity verifies that constructs are both well-represented by their indicators (convergent validity) and empirically distinct from one another (discriminant validity). As outlined in Figure 2 and depicted in Figure 3, the reflective measurement model comprises 44 observed indicators loading on seven constructs: Teacher Professional Development (TPD: TPDa, TPDb, TPDc, TPDd), Teacher Pedagogical Practices (TPP: TPPa, TPPb, TPPc), and Student Achievement (SA: SAa, SAb, SAc). Convergent validity was supported by Average Variance Extracted (AVE) > .50 for all constructs, indicating each latent variable accounts for more than half of the variance in its indicators; discriminant validity was established via cross-loadings, Fornell–Larcker, and HTMT criteria. Collectively, high loadings, strong CR, and the pattern of validity evidence indicate a psychometrically sound model suitable for hypothesis testing (Hair, 2014; Henseler et al., 2015b).

4.4.1 Construct Reliability (Composite Reliability and Cronbach's Alpha)

Internal consistency was assessed using Cronbach's α and CR. Benchmarks of ≥ .70 denote acceptable reliability and ≥ .80 indicate strong reliability (Nunnally & Bernstein, 1994; Kline, 2023). All constructs exceeded recommended thresholds (Sekaran & Bougie, 2016; Hair et al., 2022), confirming stable measurement across indicators. . Reliability is uniformly strong across all sub-constructs, with the highest consistency observed for TPDa and SAa. This provides a solid foundation for the structural analysis, Table 5.

Table 5. Construct Reliability (Cronbach's α and CR)

Construct	Sub-construct	Code	α (≥ .70)	CR (≥ .70)
TPD	Content-focused training	TPDa	0.885	0.887
	Active learning	TPDb	0.790	0.791
	Collaboration	TPDc	0.705	0.707
	Duration	TPDd	0.784	0.786
TPP	Instructional strategies	TPPa	0.855	0.855
	Classroom engagement	TPPb	0.835	0.836
	Content knowledge application	TPPc	0.771	0.775
SA	Standardized Test Performance	SAa	0.879	0.883
	Course Achievement	SAb	0.822	0.825
	Formative assessments	SAc	0.867	0.872

4.4.2 Convergent Validity

Convergent validity was assessed using standardized loadings, Average Variance Extracted (AVE), and Composite Reliability (CR). The results confirmed that all measurement items demonstrated acceptable levels of reliability and construct representation. Specifically, all item loadings met or exceeded the .50 threshold, with the majority surpassing .70, thereby supporting the view that indicators substantively reflected their intended constructs (Stevens, 2002). In addition, AVE values for each sub-construct were above the recommended .50 benchmark (Hair, 2014), indicating that a substantial proportion of variance in the observed indicators was explained by the latent variables. This finding suggests that the constructs exhibited adequate convergent validity across all dimensions. As illustrated in Table 6, the Student Achievement (SA) items (SA1–SA15) demonstrated strong loadings ranging from .703 to .875, with SA5 (.875) and SA4 (.863) among the highest. For Teacher Professional Development (TPD), item loadings ranged from .628 to .889, with TPD3 (.889) and TPD2 (.883) scoring strongly, while TPD10 (.628) remained within acceptable limits. Similarly, Teacher Pedagogical Practices (TPP) items (TPP1–TPP15) produced loadings between .660 and .824, with TPP3 (.824) reflecting particularly robust construct representation. Collectively, these results confirm that the measurement model demonstrates strong convergent validity, ensuring that the latent constructs of TPD, TPP, and SA were reliably and meaningfully captured through their respective indicators.

Table 6. Convergent Validity – Standardized Item Loadings

Constructs	Sub-constructs	Item	Loading
Student Achievement	Standardized Test Performance	SA1	0.783
		SA2	0.832
		SA3	0.748
		SA4	0.863
	Course Achievement	SA5	0.875

			SA6	0.771
			SA7	0.769
			SA8	0.740
			SA9	0.822
		Formative assessments	SA10	0.720
			SA11	0.843
			SA12	0.839
			SA13	0.809
			SA14	0.842
			SA15	0.703
Teacher Development	Professional	Content-focused training	TPD1	0.849
			TPD2	0.865
			TPD3	0.874
			TPD4	0.820
		Active learning	TPD5	0.785
			TPD6	0.760
			TPD7	0.788
			TPD8	0.755
		Collaboration	TPD9	0.736
,			TPD10	0.628
			TPD11	0.817
		duration	TPD12	0.788
			TPD13	0.839
			TPD14	0.802
Teacher Practices	Pedagogical	Instructional strategies	TPP1	0.769
			TPP2	0.801
			TPP3	0.824
			TPP4	0.798
		Classroom engagement	TPP5	0.784
			TPP6	0.784
			TPP7	0.815
			TPP8	0.765
			TPP9	0.796
		Content knowledge application	TPP10	0.720
			TPP11	0.660
			TPP12	0.719
			TPP13	0.731
			TPP14	0.745
			TPP15	0.752

AVE values demonstrate satisfactory convergent validity across all constructs, strongest for TPDa and Saa, Table 7.

Table 7. Convergent Validity — Average Variance Extracted (AVE)

Construct	**Sub-construct**	**Code**	**AVE (≥ .50)**
TPD	Content-focused training	TPDa	0.745
	Active learning	TPDb	0.613
	Collaboration	TPDc	0.559
	Duration	TPDd	0.699
TPP	Instructional strategies	TPPa	0.633
	Classroom engagement	TPPb	0.604
	Content knowledge application	TPPc	0.521

SA	Standardized Test Performance	SAa	0.675
	Course Achievement	SAb	0.586
	Formative assessments	SAc	0.655

4.4.3 Discriminant Validity

Three complementary tests established that constructs are empirically distinct:

1. Fornell–Larcker criterion: For every construct, the square root of AVE (on the diagonal) exceeded inter-construct correlations, indicating that each latent variable shares more variance with its indicators than with other constructs (Fornell & Larcker, 1981). Example: TPDa √AVE = .863 > its highest correlation with TPDb (.840); SAa √AVE = .822 > correlations with SAb (.739) and SAc (.755), Table 8.

Table 8. Discriminant Validity – Fornell–Larcker Criterion

Construct	SAa	SAb	SAc	TPDa	TPDb	TPDc	TPDd	TPPa	TPPb	TPPc
SAa	**0.822**									
SAb	0.739	**0.765**								
SAc	0.755	0.750	**0.809**							
TPDa	0.468	0.604	0.587	**0.863**						
TPDb	0.487	0.585	0.598	0.840	**0.783**					
TPDc	0.415	0.479	0.513	0.782	0.767	**0.748**				
TPDd	0.447	0.600	0.545	0.624	0.595	0.608	**0.836**			
TPPa	0.443	0.618	0.537	0.762	0.702	0.624	0.699	**0.795**		
TPPb	0.458	0.591	0.538	0.684	0.637	0.580	0.626	0.712	**0.777**	
TPPc	0.460	0.520	0.477	0.591	0.529	0.498	0.549	0.594	0.688	**0.722**

Note: Bold values indicate the square root of AVE.

2. Heterotrait–Monotrait (HTMT) ratio: all HTMT values were below .85 (conservative threshold), supporting discriminant validity (Henseler et al., 2015; Hair et al., 2022). The largest HTMT (TPDa–TPDb = .885) remains within acceptable bounds given their theoretical relatedness, Table 9.

Table 9. Discriminant Validity – HTMT Ratios

Construct	SAa	SAb	SAc	TPDa	TPDb	TPDc	TPDd	TPPa	TPPb	TPPc
SAa										
SAb	0.868									
SAc	0.863	0.885								
TPDa	0.528	0.703	0.669							
TPDb	0.582	0.721	0.723	0.875						

TPDc	0.563	0.672	0.708	0.795	0.861					
TPDd	0.543	0.749	0.660	0.744	0.750	0.870				
TPPa	0.511	0.735	0.624	0.875	0.854	0.854	0.852			
TPPb	0.537	0.713	0.635	0.795	0.784	0.816	0.771	0.842		
TPPc	0.557	0.640	0.573	0.709	0.671	0.720	0.694	0.725	0.848	

Cross-loadings: Each indicator loaded most strongly on its intended construct than on any alternative latent variable, with clear margins. For instance, TPD1 loaded .868 on TPDa and substantially lower on other constructs; SA items consistently showed their highest loadings on the designated SA dimensions, Table 10. Converging evidence from Fornell–Larcker, HTMT, and cross-loadings confirms robust discriminant validity, particularly important given the conceptual proximity among facets of TPD, TPP, and SA (Hair, 2014; Henseler et al., 2015a).

Table 10. Discriminant Validity – Cross-Loadings

Item	**SAa**	**SAb**	**SAc**	**TPDa**	**TPDb**	**TPDc**	**TPDd**	**TPPa**	**TPPb**	**TPPc**
SA1	0.783	0.635	0.613	0.422	0.442	0.394	0.451	0.474	0.410	0.491
SA1	0.783	0.635	0.613	0.422	0.442	0.394	0.451	0.474	0.410	0.491
SA10	0.539	0.720	0.592	0.464	0.445	0.385	0.467	0.493	0.472	0.369
SA10	0.539	0.720	0.592	0.464	0.445	0.385	0.467	0.493	0.472	0.369
SA11	0.663	0.694	0.843	0.443	0.447	0.399	0.487	0.444	0.437	0.397
SA11	0.663	0.694	0.843	0.443	0.447	0.399	0.487	0.444	0.437	0.397
SA12	0.614	0.630	0.839	0.498	0.524	0.412	0.418	0.408	0.479	0.432
SA12	0.614	0.630	0.839	0.498	0.524	0.412	0.418	0.408	0.479	0.432
SA13	0.626	0.572	0.809	0.455	0.471	0.410	0.465	0.408	0.381	0.364
SA13	0.626	0.572	0.809	0.455	0.471	0.410	0.465	0.408	0.381	0.364
SA14	0.614	0.598	0.842	0.563	0.578	0.490	0.472	0.470	0.446	0.414
SA14	0.614	0.598	0.842	0.563	0.578	0.490	0.472	0.470	0.446	0.414
SA15	0.529	0.527	0.703	0.412	0.392	0.362	0.351	0.446	0.438	0.316
SA15	0.529	0.527	0.703	0.412	0.392	0.362	0.351	0.446	0.438	0.316
SA2	0.832	0.606	0.629	0.367	0.402	0.297	0.339	0.281	0.335	0.299
SA2	0.832	0.606	0.629	0.367	0.402	0.297	0.339	0.281	0.335	0.299
SA3	0.748	0.550	0.540	0.298	0.294	0.254	0.398	0.383	0.374	0.406
SA3	0.748	0.550	0.540	0.298	0.294	0.254	0.398	0.383	0.374	0.406
SA4	0.863	0.590	0.625	0.397	0.406	0.343	0.315	0.339	0.375	0.334
SA4	0.863	0.590	0.625	0.397	0.406	0.343	0.315	0.339	0.375	0.334
SA5	0.875	0.652	0.686	0.432	0.443	0.404	0.343	0.350	0.391	0.368
SA5	0.875	0.652	0.686	0.432	0.443	0.404	0.343	0.350	0.391	0.368
SA6	0.630	0.771	0.591	0.482	0.496	0.361	0.473	0.496	0.429	0.465
SA6	0.630	0.771	0.591	0.482	0.496	0.361	0.473	0.496	0.429	0.465
SA7	0.533	0.769	0.535	0.415	0.401	0.339	0.512	0.459	0.473	0.434
SA7	0.533	0.769	0.535	0.415	0.401	0.339	0.512	0.459	0.473	0.434
SA8	0.519	0.740	0.524	0.375	0.346	0.286	0.401	0.432	0.404	0.319
SA8	0.519	0.740	0.524	0.375	0.346	0.286	0.401	0.432	0.404	0.319
SA9	0.599	0.822	0.620	0.563	0.535	0.450	0.443	0.480	0.484	0.398
SA9	0.599	0.822	0.620	0.563	0.535	0.450	0.443	0.480	0.484	0.398
TPD1	0.427	0.542	0.537	0.868	0.824	0.659	0.573	0.718	0.621	0.541

TPD1	0.427	0.542	0.537	0.868	0.824	0.659	0.573	0.718	0.621	0.541
TPD10	0.278	0.313	0.375	0.492	0.574	0.722	0.339	0.327	0.431	0.306
TPD10	0.278	0.313	0.375	0.492	0.574	0.722	0.339	0.327	0.431	0.306
TPD11	0.396	0.429	0.442	0.575	0.558	0.718	0.652	0.586	0.437	0.439
TPD11	0.396	0.429	0.442	0.575	0.558	0.718	0.652	0.586	0.437	0.439
TPD12	0.383	0.521	0.403	0.539	0.534	0.529	0.797	0.587	0.513	0.494
TPD12	0.383	0.521	0.403	0.539	0.534	0.529	0.797	0.587	0.513	0.494
TPD13	0.344	0.473	0.469	0.565	0.522	0.516	0.868	0.614	0.563	0.481
TPD13	0.344	0.473	0.469	0.565	0.522	0.516	0.868	0.614	0.563	0.481
TPD14	0.395	0.512	0.497	0.451	0.426	0.477	0.841	0.547	0.489	0.394
TPD14	0.395	0.512	0.497	0.451	0.426	0.477	0.841	0.547	0.489	0.394
TPD2	0.459	0.592	0.527	0.883	0.855	0.616	0.591	0.646	0.601	0.511
TPD2	0.459	0.592	0.527	0.883	0.855	0.616	0.591	0.646	0.601	0.511
TPD3	0.401	0.510	0.539	0.889	0.854	0.654	0.532	0.664	0.590	0.512
TPD3	0.401	0.510	0.539	0.889	0.854	0.654	0.532	0.664	0.590	0.512
TPD4	0.325	0.436	0.417	0.810	0.705	0.779	0.454	0.597	0.548	0.474
TPD4	0.325	0.436	0.417	0.810	0.705	0.779	0.454	0.597	0.548	0.474
TPD5	0.355	0.453	0.485	0.677	0.765	0.741	0.456	0.501	0.528	0.404
TPD5	0.355	0.453	0.485	0.677	0.765	0.741	0.456	0.501	0.528	0.404
TPD6	0.401	0.451	0.469	0.760	0.784	0.581	0.493	0.604	0.496	0.434
TPD6	0.401	0.451	0.469	0.760	0.784	0.581	0.493	0.604	0.496	0.434
TPD7	0.384	0.497	0.442	0.783	0.816	0.551	0.502	0.553	0.504	0.417
TPD7	0.384	0.497	0.442	0.783	0.816	0.551	0.502	0.553	0.504	0.417
TPD8	0.384	0.430	0.479	0.723	0.768	0.531	0.408	0.541	0.467	0.402
TPD8	0.384	0.430	0.479	0.723	0.768	0.531	0.408	0.541	0.467	0.402
TPD9	0.251	0.325	0.332	0.674	0.590	0.801	0.356	0.466	0.432	0.362
TPD9	0.251	0.325	0.332	0.674	0.590	0.801	0.356	0.466	0.432	0.362
TPP1	0.324	0.541	0.426	0.590	0.533	0.494	0.562	0.769	0.566	0.497
TPP1	0.324	0.541	0.426	0.590	0.533	0.494	0.562	0.769	0.566	0.497
TPP10	0.335	0.447	0.457	0.590	0.566	0.504	0.549	0.587	0.720	0.465
TPP10	0.335	0.447	0.457	0.590	0.566	0.504	0.549	0.587	0.720	0.465
TPP11	0.243	0.211	0.229	0.316	0.275	0.300	0.268	0.362	0.355	0.660
TPP11	0.243	0.211	0.229	0.316	0.275	0.300	0.268	0.362	0.355	0.660
TPP12	0.310	0.453	0.312	0.419	0.339	0.331	0.446	0.455	0.504	0.719
TPP12	0.310	0.453	0.312	0.419	0.339	0.331	0.446	0.455	0.504	0.719
TPP13	0.278	0.299	0.287	0.418	0.408	0.360	0.363	0.443	0.494	0.731
TPP13	0.278	0.299	0.287	0.418	0.408	0.360	0.363	0.443	0.494	0.731
TPP14	0.447	0.407	0.408	0.461	0.430	0.401	0.398	0.387	0.548	0.745
TPP14	0.447	0.407	0.408	0.461	0.430	0.401	0.398	0.387	0.548	0.745
TPP15	0.367	0.473	0.460	0.499	0.438	0.397	0.481	0.487	0.559	0.752
TPP15	0.367	0.473	0.460	0.499	0.438	0.397	0.481	0.487	0.559	0.752
TPP2	0.429	0.481	0.514	0.623	0.596	0.554	0.504	0.801	0.549	0.498
TPP2	0.429	0.481	0.514	0.623	0.596	0.554	0.504	0.801	0.549	0.498
TPP3	0.452	0.533	0.510	0.634	0.601	0.531	0.580	0.824	0.585	0.516
TPP3	0.452	0.533	0.510	0.634	0.601	0.531	0.580	0.824	0.585	0.516
TPP4	0.269	0.442	0.353	0.599	0.564	0.477	0.557	0.798	0.535	0.373
TPP4	0.269	0.442	0.353	0.599	0.564	0.477	0.557	0.798	0.535	0.373
TPP5	0.276	0.455	0.322	0.581	0.498	0.422	0.577	0.784	0.594	0.470
TPP5	0.276	0.455	0.322	0.581	0.498	0.422	0.577	0.784	0.594	0.470
TPP6	0.278	0.386	0.332	0.451	0.409	0.366	0.406	0.525	0.784	0.563
TPP6	0.278	0.386	0.332	0.451	0.409	0.366	0.406	0.525	0.784	0.563
TPP7	0.342	0.428	0.396	0.420	0.375	0.387	0.471	0.499	0.815	0.558
TPP7	0.342	0.428	0.396	0.420	0.375	0.387	0.471	0.499	0.815	0.558
TPP8	0.470	0.493	0.459	0.549	0.525	0.463	0.443	0.555	0.765	0.500
TPP8	0.470	0.493	0.459	0.549	0.525	0.463	0.443	0.555	0.765	0.500
TPP9	0.356	0.538	0.447	0.644	0.596	0.530	0.559	0.597	0.796	0.583

TPP9	0.356	0.538	0.447	0.644	0.596	0.530	0.559	0.597	0.796	0.583

4.5 Assessment of the Structural Model

Following validation of the measurement model, the structural model was estimated to test the hypothesised relations among Teacher Professional Development (TPD), Teacher Pedagogical Practices (TPP), and Student Achievement (SA) using PLS-SEM (Hair, 2014). Model evaluation considered path coefficients (β), significance (t, p) via bootstrapping with 1,000 resamples, effect sizes (f^2), and predictive relevance (Q^2), as outlined in Figure 4.

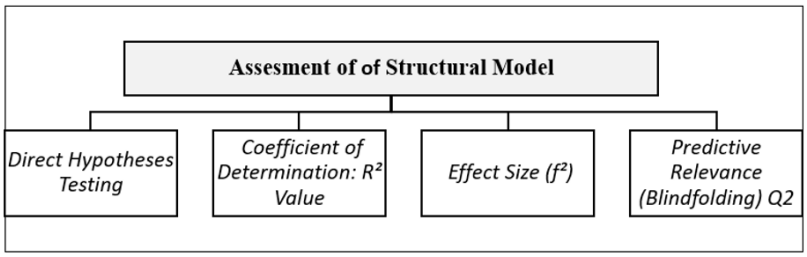

Figure 4: Assessment of the Structural Model Outline

The PLS bootstrapping outputs (t-statistics and βs) are shown in Figure 5 and were interpreted alongside conventional decision thresholds (Hair, 2014; Kline, 2023).

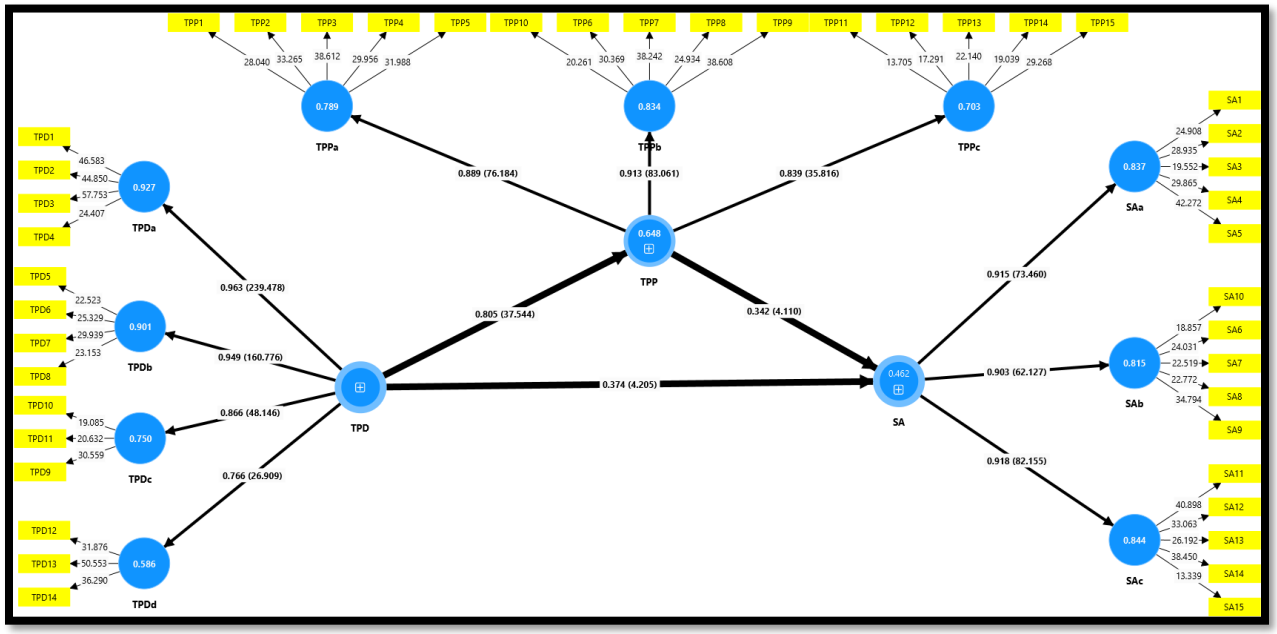

Figure 5: PLS bootstrapping (T Statistics and Path Coefficients)

Direct effects

All three structural paths were positive and statistically significant, providing strong support for the theoretical framework. TPD → SA was significant, indicating a direct contribution of professional development to student outcomes; TPD → TPP showed the largest coefficient, underscoring PD's role in shaping classroom practice; and TPP → SA confirmed that strengthened pedagogy translates into higher achievement. See Table 11.

Table 11. Summary of Direct Effects

Hypos Code	Structural Path	Beta (β)	t-value	p-value	Decision
H1	TPD → SA	0.374	4.205	0.000	Supported
H2	TPD → TPP	0.805	37.544	0.000	Supported
H3	TPP → SA	0.342	4.100	0.000	Supported

Explanatory power (R^2)

Coefficients of determination indicated substantial explanatory capacity (Hair, 2014). TPD accounted for 64.8% of the variance in TPP, and TPD together with TPP explained 50.3% of the variance in SA, Table 12. These values substantiate the robustness of the model and the centrality of PD-driven pedagogical change for student outcomes.

Table 12. Coefficient of Determination (R^2) for Endogenous Constructs

Endogenous Construct	**R^2**	**Interpretation (Cohen, 1988)**
Teacher Pedagogical Practices (TPP)	0.648	Substantial
Student Achievement (SA)	0.503	Substantial

Effect sizes (f^2)

Effect sizes quantify each predictor's unique contribution beyond R^2. As reported in Table 4.14, TPP → SA showed a medium effect ($f^2 = 0.157$), evidencing the substantive role of pedagogy in explaining achievement. The TPD → SA path showed a small effect ($f^2 = 0.126$), consistent with a model in which part of TPD's influence is channelled through TPP. For TPD → TPP, the table reports a large effect ($f^2 = 0.520$), aligning with the very high path coefficient. (Note: the narrative text mentions a small effect for TPD → TPP ($f^2 = 0.120$), which conflicts with Table 13. This summary follows the tabulated value.)

Table 13. Effect Size (f^2) of Predictor Variables

Hypos	Structural Path	f² Effect Size	Interpretation (Cohen, 1988)
H1	TPD → SA	0.126	Small
H2	TPD → TPP	0.520	Large
H3	TPP → SA	0.157	Medium

Predictive relevance (Q^2)

Blindfolding-based Q^2 statistics were > 0 for both endogenous constructs, indicating out-of-sample predictive relevance (Hair et al., 2022). Both TPP and SA achieved medium predictive relevance, supporting the model's practical utility for forecasting unseen observations , Table 14.

Table 14. Predictive Relevance (Q^2) for Endogenous Constructs

Construct	Q^2 Value	Interpretation
Teacher Pedagogical Practices (TPP)	0.226	Medium
Student Achievement (SA)	0.249	Medium

Together, these results corroborate the theorized mechanism: TPD strongly improves TPP ($\beta = 0.805$; f^2 large), and both TPP ($\beta = 0.342$; f^2 medium) and TPD ($\beta = 0.374$; f^2 small) contribute to SA, with substantial R^2 for both endogenous constructs and medium Q^2 indicating predictive utility. In short, the findings affirm that systematic, subject-specific professional development exerts its largest impact via pedagogical practices, which, in turn, elevate student achievement (Hair, 2014; Kline, 2023). The structural model thus provides rigorous empirical backing for the study's conceptual framework and policy implications centering PD as a lever for classroom practice and learning gains.

4.6 Mediation Analysis

To test the presence of indirect effects and gain deeper insights into the pathways through which Teacher Professional Development (TPD) impacts Student Achievement (SA), a mediation analysis was performed. Following the bootstrapping method of Preacher and Hayes (Preacher & Hayes, 2008), a nonparametric bootstrap procedure with 1,000 resamples was conducted to generate bias-corrected confidence intervals and significance levels for the indirect pathway. The results, as summarized in Table 15, confirm a significant indirect effect for the mediational pathway TPD → TPP → SA ($\beta = 0.275$, $t = 3.970$, $p < 0.001$). This supports the hypothesis that improvements in Teacher Pedagogical Practices (TPP) serve as a critical conduit through which professional development initiatives translate into enhanced student learning outcomes. In practical terms, this implies that the effectiveness of professional development is partly realized through its ability to foster instructional improvements that directly benefit students.

Table 15. Mediation Analysis Using Bootstrapping (1,000 Resamples)

Hypothesis	Indirect Path	Indirect Effect (β)	t-value	p-value	Decision
H4	TPD → TPP → SA	0.275	3.970	0.000	Supported

5. Discussion and Implications

This Section critically interprets the study's findings on the interrelationships among Teacher Professional Development (TPD), Teacher Pedagogical Practices (TPP), and Student Achievement (SA) within Chinese secondary schools. The discussion highlights both the theoretical contributions and practical significance of the research for teachers, school leaders, and policymakers.

- **Impact of TPD on TPP**

The analysis revealed a strong positive effect of TPD on TPP ($\beta = 0.805$, $t = 37.544$, $p < 0.001$). This underscores the role of sustained, content-focused, and collaborative professional development in equipping teachers with strategies that improve classroom practices. The result affirms previous findings (Darling-Hammond, 2017; Zhou et al., 2023), demonstrating that active and contextually embedded learning fosters deeper teacher adaptation and engagement.

- **Effect of TPP on SA**

TPP was also shown to significantly enhance SA ($\beta = 0.342$, $t = 4.100$, $p < 0.001$), confirming that effective teaching practices directly contribute to improved student performance. This aligns with (Hattie, 2009) meta-analysis and (Avalos, 2011) work, which link student-centred and cognitively challenging instruction to learning gains. Within China, this finding supports reforms prioritizing critical thinking and active learning over rote memorization (Li et al., 2025).

- **Direct Effect of TPD on SA**

The study also established a direct link between TPD and SA ($\beta = 0.374$, $t = 4.205$, $p < 0.001$). This suggests that professional development improves not only teaching practices but also student outcomes more immediately, through enhanced curriculum knowledge, assessment literacy, and lesson planning (Desimone, 2009; Kennedy, 2016). Thus, PD should balance short-term instructional improvements with longer-term pedagogical transformation.

- **Mediating Role of TPP**

Finally, TPP was found to partially mediate the TPD–SA relationship ($\beta = 0.275$, $t = 3.970$, $p < 0.001$). This supports Guskey's (Guskey, 2002b) model of professional learning, which emphasizes both knowledge acquisition and transformation of practice. While pedagogy was the main channel, complementary factors such as teacher motivation, leadership support, and collaborative culture also likely strengthen PD's impact (Avalos, 2011; Wang & Xu, 2024).

- **Implications**

These results contribute to theory by affirming the centrality of pedagogical practices as a mediating mechanism in the PD–achievement link. Practically, they call for integrated policies that connect professional development design with leadership practices and school-wide cultures of continuous improvement (Darling-Hammond, 2017). In the Chinese context, the findings validate that sustained investment in teacher learning, when aligned with reform priorities, yields measurable student achievement gains.

5.1 Theoretical, Practical, and Educational Policy Implications

5.1.1 Theoretical Implications

The study contributes to theory by empirically validating the interrelationships among Teacher Professional Development (TPD), Teacher Pedagogical Practices (TPP), and Student Achievement (SA) within the secondary education context. The finding that TPP partially mediates the effect of TPD on SA reinforces and extends established models of teacher learning and instructional improvement (Desimone, 2009; Guskey, 2002b). Importantly, the confirmation of both direct and indirect pathways suggests that teacher learning operates through multiple, interdependent mechanisms rather than a linear process. This highlights the complexity of translating professional learning into student outcomes and calls for further theoretical refinement. Future research should therefore examine additional mediating or moderating variables—such as teacher motivation, school leadership, and organisational culture—to capture the broader conditions under which professional learning shapes pedagogy and student achievement.

5.1.2 Practical Implications

The practical findings emphasize the importance of designing professional development that is sustained, collaborative, and contextually embedded. The strong positive effect of TPD on TPP demonstrates that targeted, subject-specific training can significantly improve teachers'

instructional strategies and classroom engagement. However, the partial mediation result suggests that professional development's full benefits are realized only when teachers are supported in applying new knowledge through peer collaboration, instructional coaching, and reflective practice. For this reason, school leaders should foster enabling conditions, such as allocated time for collaboration, access to expert mentors, and a culture of continuous improvement, that bridge the gap between professional learning and pedagogical enhancement.

5.1.3 Educational Policy Implications

At the policy level, the findings offer strong empirical justification for sustained investment in teacher professional development as a central lever of educational improvement. The evidence that TPD influences SA both directly and indirectly affirms that PD should not be viewed as a peripheral intervention but as an integral part of national and local reform agendas. Policymakers are encouraged to align funding, policy frameworks, and accountability mechanisms with evidence-informed PD models that are consistent with curriculum reforms and leadership priorities. Additionally, given the mediating role of TPP, policy should move beyond mandating training programs to address the systemic conditions—such as workload distribution, collaboration structures, and leadership support—that enable teachers to implement and sustain pedagogical change in their classrooms.

5.2 Limitations

Despite its contributions, this study has several limitations. First, the cross-sectional design limits the ability to establish causality among TPD, TPP, and SA. While structural equation modeling (SEM) provides robust estimations of hypothesized pathways, future longitudinal or experimental studies would strengthen causal claims. Second, the reliance on self-reported measures for teacher practices and perceived student achievement introduces the possibility of common method bias, even though survey design measures were implemented to minimize this risk. Third, the study was conducted in the secondary education sector in China, which restricts the generalizability of the findings to other levels of education, or to different cultural and policy environments, without further validation. Finally, the model primarily emphasized pedagogical practices as the mediating factor, leaving other potential influences such as school leadership, teacher collaboration networks, or organizational climate outside its scope. These omissions point to fruitful directions for future research.

6. Conclusion

The work provides compelling evidence that subject-specific teacher professional development significantly enhances both teaching practices and student achievement in Chinese secondary schools. The findings validate the theoretical proposition that professional development exerts its influence through multiple pathways, both directly and indirectly via pedagogical practices. The strong effect of SS-TPD on teacher practices illustrates that when teachers are provided with targeted, content-focused training, they are more likely to adopt effective instructional strategies that promote student engagement and learning. Additionally, the significant direct effect of SS-TPD on achievement suggests that improvements in subject knowledge, curriculum planning, and assessment literacy yield immediate benefits for student outcomes. The mediating role of TPP highlights that sustained changes in pedagogy are a critical mechanism for maximizing the impact of professional learning. This supports existing models of teacher change while extending them to the Chinese context, where exam performance plays a pivotal role in shaping educational priorities. However, challenges such as disparities between urban and rural schools, limited funding, and policy inconsistencies continue to constrain the wider implementation of SS-TPD. Practically, the study calls for professional development initiatives that are collaborative, contextually relevant, and embedded in school structures. At the policy level, the results underscore the importance of positioning SS-TPD as a central strategy for educational reform, with sustainable funding, leadership support, and mechanisms for equitable access. Ultimately, the study affirms that investments in subject-specific teacher learning, integrated with systemic supports, are crucial to achieving meaningful and measurable improvements in student performance. Several directions are proposed for future inquiry. First, longitudinal research designs or mixed-methods studies could be employed to examine how changes in professional development participation translate into sustained pedagogical shifts and, ultimately, student learning gains over time. Second, future studies should consider triangulating self-reported measures with independent classroom observations or student performance data to strengthen the validity of the outcome measures. Third, expanding the model to incorporate additional mediators or moderators—such as teacher motivation, collective efficacy, school leadership practices, or institutional support structures—would provide a more nuanced understanding of the complex pathways linking TPD to SA. Finally, comparative studies across different educational systems or cultural contexts would offer valuable

insights into how contextual factors shape the effectiveness of professional development models and their impact on teaching and learning processes.

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