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Principals' Technology Leadership and Teacher Professional Development in Under-Resourced Schools in Southwest China

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Abstract. Teacher professional development is essential for educational improvement, yet limited evidence explains how different dimensions of principals' technology leadership support teacher learning in under-resourced schools. This study examined the relationship between principals' technology leadership and teacher professional development among 474 public secondary school teachers in Southwest China selected through proportionate stratified two-stage random sampling. Technology leadership was assessed using a 22-item scale adapted from the ISTE Standards for Education Leaders, while teacher professional development was measured using a 38-item established scale. Descriptive statistics, Pearson correlation, and multiple regression were employed. Principals' technology leadership was strongly associated with teacher professional development ($r = .751$, $p < .001$), and the five dimensions jointly explained 56.5% of its variance. Equity and Citizenship Advocacy emerged as the strongest predictor ($\beta = .227$), followed by Visionary Planning ($\beta = .211$), Systems Design ($\beta = .210$), Connected Learning ($\beta = .196$), and Empowering Leadership ($\beta = .189$). By extending technology leadership research beyond technology-oriented outcomes to teacher professional development and comparing the relative contributions of its dimensions, this study provides evidence from an under-resourced context. The findings suggest that school leaders should prioritize equitable access, inclusive participation, and professional learning opportunities when advancing digital transformation.

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1. Introduction

Teacher professional development (TPD) is widely recognized as a fundamental driver of educational quality and school improvement. As educational systems respond to rapid technological change, curriculum reform, and increasingly diverse student needs, teachers are expected to continuously update their professional knowledge, pedagogical skills, and instructional practices. Effective and sustained professional development can strengthen instructional practice, reflective capacity, and teachers' ability to respond to educational change (Guskey, 2002; Darling-Hammond et al., 2017; OECD, 2019; Salo et al., 2024). Accordingly, supporting continuous teacher learning remains an important priority for educational systems undergoing digital transformation (OECD, 2025).

Access to high-quality professional learning, however, remains uneven. Teachers in under-resourced schools may face limited funding, inadequate infrastructure, restricted access to professional-learning networks, and fewer opportunities to participate in sustained training (Popova et al., 2022; Hennessy et al., 2022). Such constraints are particularly consequential in digitally transforming schools because technology can expand access to online training and collaborative learning while simultaneously reproducing existing inequalities in access, participation, and digital capability.

Recent research therefore increasingly treats digital transformation not simply as a matter of technology provision, but as an organizational and equity challenge requiring sustained support for teachers' professional learning (Huang et al., 2024; Salo et al., 2024; Zeng et al., 2025). Recent evidence from technology-supported school-based professional development further demonstrates that digital approaches can expand opportunities for sustained and collaborative teacher learning, while their effectiveness and scalability remain dependent on contextual conditions and locally available resources (Avornyo et al., 2026).

These challenges are particularly relevant to Southwest China, where schools in less-developed and rural areas continue to operate under uneven conditions of educational resources and professional-learning opportunities (Wu et al., 2019; Huang, 2020; Qin, 2022). The present study focuses on public secondary schools in Qiannan Prefecture, Guizhou Province. Provincial statistics indicate that Guizhou invested approximately RMB 166.96 billion in education in 2023, including RMB 118.62 billion in general public-budget education expenditure.

Per-student general public-budget education expenditure was approximately RMB 14,847 for junior secondary education and RMB 15,738 for senior secondary education (Guizhou Provincial Department of Education et al., 2025). These figures indicate substantial continuing public investment in education; however, aggregate provincial expenditure does not necessarily reflect equal access to technological infrastructure, professional-learning opportunities, and external support across schools and localities. Accordingly, the present study uses under-

resourced as a relative contextual characterization of schools facing constraints in these areas rather than as a classification based solely on a specific funding threshold.

School leadership is therefore an important part of the organizational context in which teachers engage in professional learning. Principals influence school priorities, resource allocation, professional collaboration, innovation, and access to learning opportunities (Leithwood et al., 2020; Hallinger et al., 2019). In digitally transforming schools, these responsibilities increasingly include technology leadership: establishing a shared vision for technology use, supporting teachers' digital practices, designing enabling organizational systems, participating in professional networks, and promoting equitable and responsible participation in digital environments (Anderson & Dexter, 2005; Raman & Thannimalai, 2019; Fernández-Batanero et al., 2022). Recent research further indicates that school leadership remains central to shaping technology-rich educational environments by aligning technological resources, organizational readiness, teacher capacity, and instructional priorities (Hsu & Chen, 2026).

Equity is especially relevant to the relationship between technology leadership and TPD in resource-constrained settings. Where access to digital resources and professional learning is uneven, leadership concerned with equitable access, inclusion, and responsible digital participation may determine whether teachers can meaningfully benefit from technology-supported learning opportunities. This perspective shifts attention from whether schools possess technology to whether school leaders create conditions in which teachers can access, use, and learn through it.

Recent evidence from rural and resource-constrained educational settings similarly highlights the importance of principals' technology leadership in addressing disparities in digital access and participation and in sustaining technology-supported educational practices under constrained conditions (Guevara-Gañas et al., 2026; Ipanag & Barrot, 2026). Related studies have increasingly connected digital leadership with teachers' technology integration, digital competence, and technology-related professional capacities (Rasdiana et al., 2024; Okunlola & Naicker, 2025; Zeng et al., 2025). Nevertheless, TPD as a broader educational outcome has received comparatively less direct attention.

Three gaps therefore motivate the present study. First, existing technology leadership research has predominantly examined technology-oriented outcomes, including ICT integration, technology adoption, and digital competence, leaving its relationship with broader TPD less established. Second, technology leadership is frequently examined as an overall construct, providing limited evidence about whether its individual dimensions contribute differently to teacher development. Third, evidence remains limited in under-resourced educational contexts, where unequal access to technology and professional learning may make equity-oriented leadership particularly consequential.

Against this background, this study examines the relationship between principals' technology leadership and TPD among public secondary school teachers in Southwest China. Specifically, it investigates teachers' perceptions of the five dimensions of principals' technology leadership, evaluates their predictive contributions to TPD, and determines which dimension demonstrates the strongest statistical contribution. In doing so, the study extends technology leadership research beyond predominantly technology-oriented outcomes, provides a dimension-level analysis of leadership contributions, and offers evidence from an under-resourced educational context that remains comparatively underrepresented in the international literature.

The study aims to examine how the five dimensions of principals' technology leadership relate to TPD in under-resourced secondary schools in Southwest China. Specifically, the objectives are:

1. To assess teachers' perceptions of the five dimensions of principals' technology leadership.
2. To evaluate the predictive contributions of the five technology leadership dimensions to TPD.
3. To determine which dimension demonstrates the strongest predictive contribution to TPD.

Accordingly, the study addresses the following research questions:

RQ1: What are teachers' perceptions of the five dimensions of principals' technology leadership in under-resourced schools in Southwest China?

RQ2: To what extent do the five dimensions of principals' technology leadership predict TPD?

RQ3: Which dimension of principals' technology leadership demonstrates the strongest predictive contribution to TPD?

2. Literature Review

Principals' technology leadership refers to the ability of school leaders to guide, organize, and maintain the effective use of digital technologies within schools. Its scope encompasses not only technology management and equipment provision but also technology-related decision-making, policy implementation, and leadership practices that integrate technology with teaching, learning, and school development. This concept is primarily influenced by Anderson and Dexter (2005) and the International Society for Technology in Education (ISTE) Standards for Educational Leaders, both of which define technology leadership as a strategic and educational leadership responsibility, rather than simply an operational management duty (Anderson & Dexter, 2005; ISTE, 2018).

Existing research generally agrees that principals' technology leadership includes several interrelated dimensions, primarily including building a vision for technology application, providing technological and organizational resources, supporting teachers' technology use and professional learning, creating a school culture of innovation, collaboration, and continuous improvement, and using technology to drive instructional improvement (Raman & Thannimalai, 2019; Fernández-Batanero et al., 2022). Recent research has continued to emphasize the

multidimensional nature of technology leadership, particularly the importance of leadership support in coordinating technological readiness, human resources, and teachers' capacity to integrate technology effectively (Hsu & Chen, 2026). Although existing studies generally support a positive role for principals' technology leadership, much of the empirical literature has concentrated on technology adoption, ICT integration, and digital competence. This emphasis has strengthened understanding of technology-related outcomes but leaves less clarity regarding whether technology leadership also contributes to broader forms of teacher learning and professional development.

In the context of digital education, the importance of principals' technology leadership is increasingly prominent. The digital transformation of schools depends not only on technology acquisition, but also on how schools guide, coordinate, and integrate technology into daily practices. Recent research indicates that principals' technology leadership is closely related to teachers' ICT integration, with its mechanisms primarily manifested in capacity building, resource provision, and cultural support (Zeng et al., 2025). Related empirical studies have also found that principals' technology leadership can actively promote teachers' technology integration and improve conditions in schools that support professional learning (Fernández-Batanero et al., 2022). Therefore, principals' technology leadership provides an important perspective for understanding how school leaders can promote teacher development in a digital education environment.

TPD generally refers to the ongoing process by which teachers enhance their professional knowledge, teaching skills, professional competence, and other teaching-related qualities. The OECD (2020; 2025) defines it as a range of activities aimed at improving teachers' skills, knowledge, expertise, and other qualities, and further emphasizes that teacher professional learning is a lifelong process of collective growth from entry into the profession. Existing research indicates that TPD is not limited to seminars or formal training but rather encompasses a broad professional growth process involving transformations in classroom practice, professional beliefs, knowledge structures, and reflective abilities. Guskey (2002) conceptualized TPD as a systematic effort aimed at improving teachers' practices, attitudes, and beliefs and, ultimately, student learning.

More recent scholarships likewise emphasize that teacher professional learning can take formal and informal, collaborative, experiential, and technology-supported forms (OECD, 2025; Salo et al., 2024). Recent evidence from technology-supported school-based professional development further suggests that blended and digitally mediated approaches can create opportunities for collaborative professional learning when they are responsive to teachers' local contexts and available technological resources (Avornyo et al., 2026). TPD is therefore broader than technology training. It includes sustained, collaborative, coherent, content-focused, and active forms of professional learning. This distinction is important because a leadership practice may support teachers' technology use without necessarily strengthening their broader professional development.

TPD is widely regarded as a crucial condition for improving teaching quality and driving school improvement. OECD research shows that most teachers believe professional development has a positive impact on teaching practice, and early analyses also indicate that high-quality professional development is closely related to more effective classroom teaching strategies. Other studies have further found that well-designed professional development can not only improve teaching practice but, under certain conditions, also enhance student learning outcomes (OECD, 2019, 2016; Darling-Hammond et al., 2017; Hennessy et al., 2022).

In the context of digital education, TPD is particularly crucial because teachers need to continuously adapt to changes in teaching methods, technological environments, and student learning needs. This need has become increasingly evident with the emergence of artificial intelligence and other rapidly evolving educational technologies, which require teachers to develop not only technical knowledge but also pedagogical judgment and the capacity to make context-sensitive decisions about technology use (Looi et al., 2026). The OECD points out that technology itself does not automatically improve learning outcomes; teacher guidance and support remain key. Therefore, TPD is considered an important outcome variable in this study because it reflects teachers' ability to continuously adapt, learn, and improve their professional practices in the face of educational change (OECD, 2025, 2020).

Existing evidence suggests several plausible links between technology leadership and TPD. Visionary Planning may align professional learning with school goals; Empowering Leadership may encourage teacher agency and experimentation; Systems Design may provide the organizational infrastructure needed for sustained learning; Connected Learning may expand access to professional networks; and Equity and Citizenship Advocacy may reduce unequal access to digital resources and learning opportunities. However, the available literature does not clearly establish whether these dimensions contribute equally to TPD, especially in under-resourced settings. This unresolved issue provides the basis for the present dimension-level analysis.

3. Methodology

This study employed a quantitative cross-sectional survey design to examine the relationships and predictive contributions of principals' technology leadership dimensions to TPD in under-resourced secondary schools in Southwest China. The cross-sectional design enabled the examination of associations among the study variables at a single point in time; therefore, the findings are interpreted as predictive associations rather than evidence of causal effects. Self-administered questionnaires were used to obtain teachers' perceptions of principals' technology leadership and their professional development experiences.

3.1 Participants and Sampling

This study was conducted in Qiannan Prefecture, Guizhou Province, Southwest China. In the present study, under-resourced is used as a relative contextual characterization rather than as a classification based on a single school-level

expenditure threshold. Specifically, it refers to educational settings in which access to technological infrastructure, sustained professional-learning opportunities, and external educational support may be comparatively constrained. This distinction is important because provincial-level education expenditure does not necessarily capture variation in resource availability across individual schools and localities.

The target population consisted of 11,591 teachers employed in public secondary schools across Qiannan Prefecture. A proportionate stratified two-stage random sampling technique was employed to ensure adequate representation of teachers from different school levels and locations. Based on the sample size recommendations of Krejcie and Morgan (1970), a minimum sample size of 384 respondents was required for the study.

A total of 500 questionnaires were distributed to teachers across selected schools, and 474 valid responses were returned and retained for analysis, yielding a response rate of 94.8%. The final sample exceeded the minimum required sample size and was considered adequate for the statistical analyses conducted in this study. Participants represented a diverse range of demographic backgrounds, including differences in gender, age, teaching experience, academic qualifications, and teaching disciplines.

To assess potential non-response bias, an early-late respondent comparison was conducted. Respondents were ordered according to questionnaire submission time, and the earliest 25% ($n = 119$) and latest 25% ($n = 119$) were compared on the two principal study constructs. Independent-samples *t*-tests indicated no statistically significant differences between early and late respondents in principals' technology leadership, $t(236) = -0.282$, $p = .778$, or TPD, $t(236) = -1.564$, $p = .119$. The corresponding effect sizes were small (Cohen's $d = -0.037$ and -0.203 , respectively). Together with the high valid response rate of 94.8%, these findings provided no indication of substantial non-response bias.

3.2 Research Instruments

Data were collected using a structured questionnaire consisting of three sections. The first section gathered demographic information, including gender, age, teaching experience, educational qualification, teaching subject, and administrative position. The second section measured principals' technology leadership, while the third section assessed TPD. All items were rated on a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), with higher scores indicating stronger agreement with the statements.

Principals' technology leadership was measured using a scale adapted from Yuting et al. (2022), which was developed based on the ISTE Standards for Education Leaders (ISTE, 2018). The instrument consisted of 22 items representing five dimensions of technology leadership: Equity and Citizenship Advocate, Visionary Planning, Empowering Leadership, Systems Design, and Connected Learning.

These dimensions represent complementary yet distinct aspects of principals' technology leadership. Visionary Planning focuses on establishing a shared vision for technology use and digital transformation. Empowering Leadership emphasizes supporting teachers' participation, innovation, and professional learning. Systems Design reflects the development of organizational structures and technological infrastructure that support educational improvement. Connected Learning highlights principals' engagement in continuous professional learning and professional networking. Equity and Citizenship Advocate focuses on promoting equitable access to digital resources, responsible technology use, and inclusive participation in technology-enhanced learning opportunities. Given the objectives of the present study, particular attention was paid to examining the relative contribution of these dimensions to TPD.

TPD was measured using the TPD Scale developed by Main and Pendergast (2015). The instrument consisted of 38 items assessing five dimensions of effective professional development: Duration, Collective Participation, Coherence, Content Focus, and Active Learning. These dimensions reflect widely recognized characteristics of high-quality professional development. Duration refers to the extent and continuity of professional-learning activities. Collective Participation captures opportunities for teachers to engage in collaborative learning with colleagues. Coherence reflects the alignment of professional development activities with teachers' professional needs and school goals. Content Focus assesses the relevance of professional learning to subject matter and instructional practice, while Active Learning refers to teachers' engagement in interactive and practice-oriented learning experiences. Higher scores indicated stronger engagement in effective professional development practices.

3.3 Validity and Reliability

Several procedures were undertaken to establish the validity and reliability of the research instruments Before the main data collection. First, the questionnaire was translated into Chinese and reviewed by two language experts with doctoral qualifications and extensive experience in academic writing and translation. Subsequently, three experts in educational leadership and related fields evaluated the instrument to assess the relevance, clarity, and appropriateness of the items. Revisions were made based on their recommendations to improve linguistic accuracy and contextual suitability.

Confirmatory factor analysis (CFA) was subsequently conducted to assess the measurement structure of the constructs examined in the present study. The 10-factor measurement model comprised the five dimensions of principals' technology leadership and the five dimensions of TPD. The model demonstrated satisfactory overall fit: $\chi^2(1665) = 2117.699$, $\chi^2/df = 1.272$, CFI = .971, TLI = .970, RMSEA = .024 (90% CI [.021, .027]), and SRMR = .032. Standardized factor loadings ranged from .654 to .849. Average variance extracted (AVE) values ranged from .515 to .651, while composite reliability (CR) values ranged from .818 to .929, providing evidence of satisfactory convergent validity and construct reliability. In addition, the square root of the AVE for each construct exceeded its correlations with the other constructs, supporting discriminant validity.

A pilot study was then conducted with secondary school teachers who were not included in the final sample. The pilot study aimed to evaluate item clarity, administration procedures, internal consistency reliability, and preliminary construct validity. The pilot participants were selected to reflect the characteristics of the target population while avoiding overlap with the main survey respondents. Reliability was assessed using Cronbach's alpha coefficients. The pilot results indicated satisfactory internal consistency across all dimensions of principals' technology leadership, TPD, and the related measurement scales, with Cronbach's alpha values ranging from 0.731 to 0.924, exceeding the recommended threshold of 0.70.

Construct validity was examined through exploratory factor analysis (EFA). The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.944, indicating excellent suitability for factor analysis. Bartlett's Test of Sphericity was statistically significant, and the analysis extracted 14 factors corresponding to the theoretically expected dimensions of the study constructs. All primary factor loadings exceeded 0.50, providing evidence of satisfactory construct validity. Based on these results, the instruments were considered valid and reliable for use in the main study.

3.4 Common Method Bias Assessment

Because principals' technology leadership and TPD were assessed using self-reported data collected from the same respondents at a single point in time, potential common method bias was considered. Several procedural measures were incorporated into the data-collection process to reduce response-related bias. Participation was voluntary, respondents were informed that their responses would remain confidential and would be used only for research purposes, no personally identifiable information was collected, and participants were informed of their right to withdraw from the study without penalty.

In addition, Harman's single-factor test was conducted as a statistical assessment of potential common method bias. All 60 measurement items used in the present study, comprising 22 items measuring principals' technology leadership and 38 items measuring TPD, were entered into an unrotated EFA. The first factor accounted for 29.253% of the total variance, which was below the commonly used 50% reference threshold. Thus, no single factor accounted for the majority of the variance in the measurement items, suggesting that common method bias was unlikely to constitute a serious threat to the interpretation of the study findings. Nevertheless, given the single-source and cross-sectional nature of the data, common method bias cannot be completely ruled out and is acknowledged as a limitation of the study.

3.5 Collection and Ethical Considerations

Data collection was conducted after completion of the instrument validation and pilot study procedures. Before survey administration, permission was obtained from the relevant educational authorities and participating schools. Twenty public secondary schools, including both junior and senior secondary schools, were included through the proportionate stratified two-stage random sampling procedure.

The final Chinese-language questionnaire was administered through an online survey platform. School administrators or designated coordinators assisted in distributing the survey link to eligible teachers. Participation was voluntary. Before completing the questionnaire, respondents were informed about the study's purpose, voluntary participation, confidentiality, their right to withdraw without penalty, and the use of the data for research purposes only. No personally identifiable information was collected. A total of 500 questionnaires were distributed, of which 474 valid responses were retained for analysis, resulting in a valid response rate of 94.8%. Returned questionnaires were screened for completeness and consistency before statistical analysis.

3.6 Data Analysis

Data was analyzed using IBM SPSS Statistics Version 26. Descriptive statistics, including means and standard deviations, were used to examine teachers' perceptions of the five dimensions of principals' technology leadership and TPD. Multiple regression analysis was conducted to assess the predictive effects of the five technology leadership dimensions on TPD and to determine their relative contributions. Standardized beta coefficients were used to compare the strength of the predictors. Reliability analysis using Cronbach's alpha coefficients was performed to evaluate the internal consistency of the measurement scales. Statistical significance was determined at the 0.05 level.

4. Results and Findings

4.1 Demographic Characteristics of Respondents

A total of 474 teachers were included in the analysis. Of the respondents, 43.46% were male and 56.54% were female. Participants represented a range of age groups, teaching experience, educational qualifications, subject specializations, and professional positions. Most respondents held a bachelor's degree (91.14%), while 86.50% were general classroom teachers. The demographic characteristics indicate that the sample included teachers with varied professional and educational backgrounds.

4.2 Teachers' Perceptions of Principals' Technology Leadership

As shown in Table 1, the overall mean score for principals' technology leadership was 3.882 (SD = .500). Among the five dimensions, Empowering Leadership had the highest mean (M = 4.036, SD = .668), followed by Equity and Citizenship Advocate (M = 3.960, SD = .737) and Visionary Planning (M = 3.905, SD = .703). Systems Design (M = 3.766, SD = .639) and Connected Learning (M = 3.744, SD = .684) showed comparatively lower mean scores.

Table 1: Descriptive Statistics for Principals' Technology Leadership

Dimension	Mean	SD
Equity and Citizenship Advocate	3.960	0.737
Visionary Planning	3.905	0.703
Empowering Leadership	4.036	0.668
Systems Design	3.766	0.639
Connected Learning	3.744	0.684
Overall PTL	3.882	0.500

4.3 TPD

Table 2 presents the descriptive statistics for TPD. The overall TPD mean was 3.907 (SD = .456). Content Focus had the highest mean (M = 3.996, SD = .636), followed by Active Learning (M = 3.959, SD = .600) and Collective Participation (M = 3.954, SD = .676). Duration (M = 3.842, SD = .702) and Coherence (M = 3.786, SD = .575) had comparatively lower mean scores.

Table 2: Descriptive Statistics for TPD

Dimension	Mean	SD
Duration	3.842	0.702
Collective Participation	3.954	0.676
Coherence	3.786	0.575
Content Focus	3.996	0.636
Active Learning	3.959	0.600
Overall TPD	3.907	0.456

4.4 Association Between Principals' Technology Leadership and TPD

Pearson product-moment correlation analysis showed a statistically significant positive association between principals' technology leadership and TPD, $r = .751$, $p < .001$ (Table 3). Thus, higher perceived levels of principals' technology leadership were associated with higher levels of TPD.

Table 3: Correlation Between PTL and TPD

Variable	1	2
Principals' Technology Leadership	1	
TPD	0.751***	1

4.5 Predictive Contributions of Technology Leadership Dimensions to TPD

Multiple linear regression analysis was conducted to examine the predictive contributions of the five dimensions of principals' technology leadership to TPD. The overall regression model was statistically significant, $F = 121.414$, $p < .001$, and explained 56.5% of the variance in TPD ($R^2 = .565$; adjusted $R^2 = .560$).

All five dimensions of principals' technology leadership were statistically significant positive predictors of TPD. Equity and Citizenship Advocate demonstrated the strongest standardized predictive contribution ($\beta = .227$, $t = 6.163$, $p < .001$), followed by Visionary Planning ($\beta = .211$, $t = 5.828$, $p < .001$), Systems Design ($\beta = .210$, $t = 5.827$, $p < .001$), Connected Learning ($\beta = .196$, $t = 5.091$, $p < .001$), and Empowering Leadership ($\beta = .189$, $t = 5.215$, $p < .001$).

Multicollinearity diagnostics indicated no problematic collinearity among the predictors. VIF values ranged from 1.391 to 1.598, while tolerance values ranged from .626 to .719. Overall, the findings indicate that all five dimensions made significant positive contributions to TPD, with Equity and Citizenship Advocate showing the largest standardized regression coefficient.

Table 4: Predictive Effects of PTL Dimensions on TPD

Predictor	B	SE	β	t	p	VIF	Tolerance
Constant	1.243	0.111	—	11.242	< .001	—	—
Equity and Citizenship Advocate	0.151	0.025	0.227	6.163	< .001	1.457	0.686
Visionary Planning	0.137	0.024	0.211	5.828	< .001	1.415	0.707
Empowering Leadership	0.129	0.025	0.189	5.215	< .001	1.410	0.709
Systems Design	0.150	0.026	0.210	5.827	< .001	1.391	0.719
Connected Learning	0.121	0.024	0.196	5.091	< .001	1.598	0.626
F	121.414*						
R ²	0.565						
Adjusted R ²	0.560						

Note. Dependent variable = TPD.

$p < .05$, $p < .01$, $p < .001$.

5. Discussion

5.1 Principals' Technology Leadership in Under-Resourced Schools

The findings showed that teachers perceived a relatively high level of principals' technology leadership across the participating secondary schools. This suggests that technology-related leadership practices were visible even within a comparatively resource-constrained educational context. The finding is consistent with previous research showing that technology leadership has become increasingly important as schools respond to digital transformation and the growing use of technology in teaching and learning (Anderson & Dexter, 2005; Raman & Thannimalai, 2019).

More recent scholarship reinforces this perspective by conceptualizing technology leadership as a multidimensional leadership responsibility involving strategic direction, professional capacity, organizational support, systemic improvement, and digital citizenship (Jin et al., 2026). At the same time, recent evidence indicates that inadequate digital infrastructure and limited digital competence continue to constrain principals' capacity to integrate and support digital technologies effectively (Qu & Mydin, 2026). Therefore, the relatively positive perceptions identified in the present study should not be interpreted as evidence that resource constraints have been eliminated. Rather, they suggest that principals can enact recognizable technology leadership practices even when schools operate under comparatively constrained conditions.

Among the five dimensions, Empowering Leadership was perceived most strongly, followed by Equity and Citizenship Advocacy and Visionary Planning. The prominence of Empowering Leadership supports the view that technology leadership extends beyond the provision of technological infrastructure to include creating organizational conditions that encourage teacher participation, collaboration, experimentation, and professional learning. Evidence from Malaysian secondary schools similarly highlights the relevance of principals' technology leadership and professional development to teachers' technology-related practices (Thannimalai & Raman, 2018). Although that study focused on technology integration rather than TPD as the focal outcome, it provides a useful

comparison from a developing educational context outside China and reinforces the broader connection between technology leadership and teacher learning.

The relatively strong perception of Equity and Citizenship Advocacy is particularly meaningful in an under-resourced context. Digital inequality involves not only physical access to devices and connectivity but also differences in digital skills, participation, and opportunities to benefit from technology (van Dijk, 2020; UNESCO, 2023). Evidence from resource-constrained educational settings outside China likewise indicates that technological infrastructure, leadership support, and school-level planning can shape schools' capacity to benefit from digital technologies.

More recent evidence from rural Indigenous schools in the Peruvian Amazon similarly demonstrates that stronger principals' technological leadership is associated with more favorable school digital conditions, while qualitative findings highlight the importance of managing scarce resources, consistently supporting teachers, and mobilizing community participation under constrained conditions (Guevara-Goñas et al., 2026). These findings provide a useful international comparison with the present study and reinforce the importance of considering technology leadership in relation to contextual inequalities rather than technological provision alone.

Systems Design and Connected Learning received comparatively lower ratings, but this should not be interpreted as evidence that these leadership functions are unimportant. One possible explanation is that system coordination, infrastructure-related leadership, and professional networking activities may be less directly visible to classroom teachers than practices involving empowerment, participation, and access. Because the present study did not directly examine the visibility of different leadership practices, however, this interpretation remains tentative. Taken together, the findings portray technology leadership as a multidimensional practice whose enactment may take different forms depending on the organizational and resource conditions of schools.

5.2 Technology Leadership and TPD

The findings revealed a strong positive association between principals' technology leadership and TPD, suggesting that teachers who perceived stronger technology leadership also tended to report more positive professional development experiences. This finding is consistent with the broader view that school leadership can shape the organizational conditions within which teacher learning occurs. Technology leadership may be particularly relevant because it extends beyond the provision of digital tools to include the development of shared visions, organizational support, professional collaboration, and opportunities for technology-supported learning. Banoğlu et al. (2023), for example, found that principals' technology leadership practices were associated with learning-organization cultures that supported teachers' individual and collective professional learning. Their findings reinforce the view that technology leadership may be connected to teacher development through the broader professional-learning environment created within schools.

Nevertheless, previous research does not indicate that technology leadership produces uniformly strong teacher outcomes across settings. For example, research in Malaysian secondary schools found a moderate relationship between principals' technology leadership and teachers' ICT self-efficacy. Technology leadership explained only part of the variation in teachers' confidence in using technology (Omar & Ismail, 2021). Related research has also examined technology leadership primarily in relation to technology integration rather than professional development itself (Raman & Thannimalai, 2019).

These differences are important because teacher outcomes such as ICT integration, technology self-efficacy, and professional development are conceptually distinct. Technology-specific practices may depend strongly on teachers' prior digital competence, access to infrastructure, and classroom conditions, whereas professional development also encompasses collaboration, sustained learning, content-focused learning, coherence, and active participation. Consequently, the relationship between technology leadership and teacher outcomes should not be assumed to be uniform across constructs or educational contexts.

Context may also help explain variation across studies. In resource-constrained settings, limitations in infrastructure, professional-learning opportunities, and external support can restrict teachers' access to development opportunities. Under such conditions, leadership practices that organize available resources, support collaboration, broaden access to learning opportunities, and establish shared priorities may assume greater relevance. Conversely, technology leadership alone cannot compensate for all structural constraints. Evidence from other developing and resource-constrained educational settings indicates that inadequate infrastructure, insufficient training, and weak organizational support can continue to inhibit effective technology use even when schools are actively pursuing digitalization. This suggests that technology leadership is better understood as one component of a broader organizational environment for teacher learning rather than as an independent solution to resource limitations.

The present findings therefore extend previous research in an important way. Much of the existing technology-leadership literature has concentrated on technology adoption, ICT integration, or teachers' technology-related self-efficacy. By focusing directly on TPD, this study suggests that the relevance of principals' technology leadership may extend beyond teachers' use of digital tools to the wider professional-learning environment of the school. At the same time, because the present study employed cross-sectional self-report data, the observed relationship should not be interpreted causally. The findings indicate a substantial association between the two constructs, but longitudinal and multi-source research is needed to determine how technology leadership and TPD may influence one another over time.

5.3 Differential Contributions of Technology Leadership Dimensions

The dimension-level findings indicate that all five components of principals' technology leadership were positively associated with TPD when considered simultaneously. This pattern supports a multidimensional understanding of

technology leadership: teacher professional learning may be related not to a single leadership behavior, but to a combination of equity-oriented leadership, strategic planning, empowerment, organizational systems, and leaders' own engagement in continuous learning. This interpretation is consistent with recent systematic evidence conceptualizing K-12 administrators' technology leadership as a multidimensional responsibility encompassing strategic direction, professional capacity, supportive organizational conditions, systemic improvement, and digital citizenship (Jin et al., 2026). At the same time, the differences among the dimensions suggest that these leadership practices may relate to TPD through somewhat different organizational processes. This interpretation is also consistent with previous research indicating that technology leadership should not be treated as a unitary set of practices and that particular leadership dimensions may assume different levels of relevance depending on the organizational context and teacher outcome examined (Banoğlu et al., 2023).

Visionary Planning and Systems Design both showed comparatively substantial contributions. Their similar importance is noteworthy because they represent complementary aspects of technology leadership. Visionary Planning concerns establishing shared directions and priorities for technology-supported learning, whereas Systems Design concerns building and sustaining the organizational and technological conditions through which such priorities can be implemented. The latter includes attention to infrastructure, resource support, data and privacy practices, and partnerships that sustain technology-supported learning.

The ISTE framework similarly conceptualizes Systems Designer as a leadership role concerned with building teams and systems, ensuring sufficient and scalable resources, and developing organizational arrangements that support effective technology use. In an under-resourced context, Systems Design is particularly important. Teachers' access to professional learning may depend not only on their willingness to participate but also on whether schools have effective systems for providing and sustaining access to technology, support, and learning opportunities.

Connected Learning also warrants particular attention. Within the technology-leadership framework, a Connected Learner is expected to remain current with emerging technologies and pedagogical developments, participate in professional-learning networks, engage in technology-supported reflection, and develop the capacity to lead continuous improvement. From the perspective of TPD, this dimension may be especially relevant in schools with limited internal professional learning resources. Principals who engage with external professional networks and emerging knowledge may be better positioned to expose their schools to ideas, expertise, and learning opportunities that are not readily available locally. In this sense, connected learning may function as a form of organizational boundary spanning: digital professional networks can potentially extend the professional knowledge resources available to a school beyond its immediate institutional environment. This interpretation should remain cautious, however, because the present study measured teachers' perceptions of leadership

practices rather than the actual structure or use of principals' professional networks.

Empowering Leadership, although perceived strongly by teachers at the descriptive level, showed a comparatively smaller unique contribution when the other technology leadership dimensions were considered simultaneously. This distinction illustrates why descriptive prominence should not be equated with predictive importance. Empowering practices may overlap conceptually and organizationally with other leadership functions—for example, teacher participation may be supported by equitable access, shared planning, appropriate systems, and connected professional learning. Consequently, its smaller unique contribution does not imply that empowerment is unimportant; rather, it indicates that its distinctive statistical contribution was more limited after the other dimensions were taken into account.

Taken together, these findings suggest that technology leadership for TPD is best understood as an interrelated leadership configuration rather than a hierarchy in which one set of practices renders the others unnecessary. Strategic direction requires organizational systems for implementation; systems require teachers who are empowered to participate; and connected learning can broaden access to knowledge and professional networks. Within this broader configuration, Equity and Citizenship Advocacy emerged as particularly noteworthy. Its relative importance is considered separately in the following section because it speaks directly to the study's central contribution concerning technology leadership in under-resourced educational settings.

This interpretation is reinforced by recent evidence showing that inadequate digital infrastructure—including insufficient devices, unstable connectivity, and outdated equipment—can restrict principals' ability to create supportive conditions for teachers' effective use of digital technologies (Qu & Mydin, 2026). Systems Design may therefore be particularly consequential in resource-constrained settings because it concerns not only the presence of technology, but also the organizational arrangements required to make technological resources and professional support usable and sustainable.

5.4 The Critical Role of Equity and Citizenship Advocacy

Equity and Citizenship Advocacy emerged as the strongest predictor of TPD among the five dimensions of principals' technology leadership. Although the differences among the standardized contributions were relatively modest, the prominence of this dimension is theoretically meaningful in the context of under-resourced schools. Within the ISTE framework, Equity and Citizenship Advocacy emphasizes the use of technology to promote equity, inclusion, responsible digital participation, and access to meaningful technology-supported learning opportunities. These responsibilities may assume particular importance where access to technological resources and professional-learning opportunities is uneven.

One possible explanation is that, in resource-constrained schools, equity-oriented technology leadership may shape not only access to digital tools but also teachers' opportunities to participate in professional learning. Teachers cannot benefit equally from technology-supported professional development when access to connectivity, digital resources, training, or opportunities for participation is uneven. From this perspective, equity-oriented leadership may help create conditions in which professional-learning opportunities become more accessible across different groups of teachers.

This interpretation is consistent with broader scholarship on digital inequality, which emphasizes that the digital divide involves both physical access and differences in skills, participation, and the capacity to convert technological access into meaningful educational benefits (van Dijk, 2020; UNESCO, 2023). Importantly, recent empirical evidence from rural Indigenous schools has similarly shown that stronger principals' technological leadership is associated with more favorable digital conditions in contexts characterized by limited infrastructure, unstable connectivity, and insufficient teacher preparation (Guevara-Goñas et al., 2026). Such evidence strengthens the interpretation that technology leadership may become particularly consequential when educational opportunities are unevenly distributed.

The finding also broadens the conventional interpretation of technology leadership. Much of the earlier literature has emphasized technology infrastructure, strategic planning, technology integration, and leaders' capacity to facilitate digital change. The present findings suggest that, for TPD in under-resourced settings, the distribution of opportunities may be as important as the availability of technology itself. In other words, the leadership challenge is not simply whether schools possess digital resources, but whether teachers have meaningful and sufficiently inclusive opportunities to access and benefit from those resources. Recent research on technology leadership among public secondary school principals similarly illustrates how leaders must navigate questions of access, teacher support, organizational coordination, and persistent digital inequalities while sustaining technology-related practices (Ipanag & Barrot, 2026). The present findings extend this perspective by suggesting that such leadership conditions may also be relevant to teachers' broader professional development rather than only to technology integration itself.

At the same time, the relative prominence of Equity and Citizenship Advocacy should not be interpreted as evidence that it operates independently of the other technology leadership dimensions. The differences in predictive contribution across the five dimensions were relatively small, and professional development is likely to be supported through their combined operation. Equity-oriented intentions require strategic planning to become actionable, organizational systems to make resources accessible and sustainable, empowerment to support teachers' professional agency, and connected learning to broaden access to professional knowledge and networks. The finding therefore points less to the dominance of a single leadership dimension than to the particular salience of equity within a broader configuration of technology leadership practices.

This interpretation represents an important contribution of the study. Existing technology leadership research has frequently examined whether principals facilitate technology adoption or teachers' technology integration. By focusing on TPD, the present study draws attention to a different question: how technology leadership may relate to teachers' opportunities to learn and develop professionally. In under-resourced educational settings, the findings suggest that equity should be considered not merely as an ethical principle of digital leadership but as a potentially important organizational condition associated with teacher learning. Nevertheless, because the study was cross-sectional and based on teachers' perceptions, the mechanisms proposed here remain interpretive rather than causal. Future longitudinal and qualitative research could examine more directly how principals' equity-oriented practices shape teachers' actual access to and participation in professional-learning opportunities.

6. Implications

6.1 Theoretical Implications

This study extends the theoretical scope of principals' technology leadership beyond predominantly technology-oriented outcomes, such as ICT integration, technology adoption, and digital competence, by positioning TPD as an important educational outcome. The findings therefore support a broader view of technology leadership as a multidimensional form of school leadership. It involves not only managing and implementing digital technologies but also creating conditions that support teachers' learning, collaboration, and professional development.

A second theoretical contribution concerns the differentiated roles of the five technology leadership dimensions. The findings suggest that technology leadership should not be conceptualized as a uniform set of practices whose dimensions contribute identically to TPD. Rather, Visionary Planning, Systems Design, Empowering Leadership, Connected Learning, and Equity and Citizenship Advocacy represent complementary leadership functions that may support professional learning through different organizational conditions. In particular, the meaningful contribution of Systems Design indicates that organizational infrastructure, resource coordination, and support systems should not be treated as merely technical background conditions. They form part of the leadership environment within which sustained professional learning becomes possible. This interpretation also corrects the earlier characterization of Systems Design as theoretically weaker and reinforces the multidimensional nature of technology leadership.

The prominence of Equity and Citizenship Advocacy further develops the theoretical relationship between digital citizenship and TPD. Within technology leadership, digital citizenship extends beyond responsible or ethical technology use to encompass equitable access, inclusive participation, and the capacity of members of the school community to benefit meaningfully from digital opportunities. From a professional-development perspective, these principles are relevant because access to digital resources alone does not ensure access to professional learning. Teachers also require meaningful opportunities to

participate in online learning, professional networks, collaborative activities, and technology-supported forms of professional inquiry. Equity and digital citizenship can therefore be understood as organizational conditions that shape who is able to participate in and benefit from digitally supported professional learning.

Importantly, Equity and Citizenship Advocacy should not be interpreted as operating independently of the other technology leadership dimensions. Its comparatively strong contribution is better understood as indicating the particular salience of equity within an interdependent leadership configuration. Equitable participation requires strategic planning, sustainable organizational systems, teacher empowerment, and access to professional networks. The study therefore shifts the theoretical emphasis from “leadership for technology” toward a broader understanding of technology leadership for equitable professional learning, while retaining the multidimensional structure of the ISTE-informed framework.

Finally, evidence from an under-resourced setting in Southwest China extends a literature that has often been developed within better-resourced or Western educational systems. The findings do not imply that the same dimensional pattern will necessarily occur across all settings. Rather, they suggest that the relative salience of particular technology leadership practices may depend on contextual conditions such as resource availability, professional-learning infrastructure, and opportunities for digital participation. This context-sensitive perspective provides a basis for future comparative research across rural, developing, and resource-constrained educational systems.

6.2 Practical Implications

The findings offer several practical implications for school leaders, educational authorities, and policymakers seeking to strengthen TPD in under-resourced schools. At the school level, principals should move beyond treating technology leadership primarily as equipment provision or technical management. Instead, they should identify disparities in teachers’ access to digital resources and professional-learning opportunities, establish transparent procedures for allocating available resources, and ensure that teachers with different levels of experience and digital competence can participate meaningfully in technology-supported professional-learning.

Equity and Citizenship Advocacy can be translated into concrete practices by monitoring participation in online training, professional-learning communities, digital curriculum development, and other technology-supported learning activities. Where participation gaps exist, principals can use targeted scheduling, shared-device arrangements, peer mentoring, and school-based training to reduce barriers. Digital citizenship development should also extend beyond internet safety to include data privacy, ethical use and sharing of digital resources, responsible professional communication, critical evaluation of digital information, and inclusive online participation.

Connected Learning is particularly relevant to rural and geographically dispersed schools. Educational authorities and school leaders could establish cross-school professional-learning networks through online communities of practice, joint lesson planning, peer mentoring, virtual workshops, and subject-specific learning groups. Such networks can provide sustained access to expertise and professional collaboration beyond individual schools while reducing reliance on one-off external training.

Technology investment should also be aligned with professional-learning priorities. Rather than allocating limited budgets primarily to hardware, educational authorities should consider funding packages that combine essential infrastructure and connectivity with TPD, principal capacity building, technical assistance, and cross-school networks. Schools could develop annual digital professional-learning plans specifying teacher-learning priorities, available resources, support responsibilities, and indicators of participation. Where funding is extremely limited, shared infrastructure, reusable digital resources, peer-led training, and inter-school resource sharing can help sustain professional learning, although such approaches should complement rather than substitute for adequate public investment.

These implications may also be relevant to other rural, developing, and resource-constrained educational systems. Specific implementation strategies should be adapted to local infrastructure, funding, and institutional conditions. Nevertheless, the broader principle is transferable: technology investment is more likely to support TPD when leadership simultaneously addresses equitable access, organizational support, professional connection, and meaningful participation.

7. Conclusion

7.1 Conclusions

This study examined principals' technology leadership and its relationship with TPD in under-resourced secondary schools in Southwest China. The findings extend the role of technology leadership beyond technology implementation by demonstrating its relevance to teachers' professional learning. Collectively, the five dimensions of principals' technology leadership explained 56.5% of the variance in TPD, indicating the substantial relevance of technology leadership to teacher development in the participating schools.

Among the five dimensions, Equity and Citizenship Advocacy emerged as the strongest predictor of TPD, although the differences in predictive contribution across dimensions were relatively modest. This finding highlights the particular importance of equitable access, inclusion, and meaningful participation in technology-supported professional learning in resource-constrained educational environments. At the same time, the significant contributions of all five dimensions reinforce the multidimensional nature of technology leadership and suggest that equity-oriented practices should operate alongside strategic planning, organizational support, teacher empowerment, and professional connectedness.

The broader significance of these findings extends beyond the immediate context of Southwest China. Although these findings may not apply equally across all education systems, they suggest that technology leadership is particularly important in rural and resource-constrained settings when digital transformation provides equitable opportunities for teacher learning. For school practitioners, the central takeaway is clear: effective technology leadership should not focus solely on providing or promoting technology, but on ensuring that teachers can access, participate in, and benefit from the professional-learning opportunities that technology makes possible.

7.2 Limitations

Several limitations should be considered when interpreting the findings of this study. First, the study employed a cross-sectional survey design. Although significant relationships were identified between principals' technology leadership and TPD, the design does not permit causal conclusions regarding the direction of these relationships. Longitudinal research is therefore needed to examine whether and how changes in technology leadership are associated with changes in TPD over time.

Second, the study relied on teachers' self-reported perceptions of both principals' technology leadership and their own professional development. Although the assessment of common method bias did not indicate that a single method factor adequately accounted for the observed relationships, reliance on a single respondent source remains a methodological limitation. Future studies could incorporate multiple sources of evidence, including principal reports, interviews, observations, professional-development records, and other school-level data.

Third, the study was conducted in under-resourced secondary schools within a specific region of Southwest China. The findings therefore reflect particular socioeconomic, institutional, and digital-development conditions and should not be generalized uncritically to other regions or national systems. Comparative research is required to determine whether the relative importance of technology leadership dimensions, particularly Equity and Citizenship Advocacy, is similar in other rural and resource-constrained educational contexts.

Finally, the present study did not separately examine whether the relationships between technology leadership and TPD differed between junior and senior secondary schools. Consequently, no conclusions can be drawn regarding school-level differences from the present data. This distinction warrants examination in future research because organizational conditions, teacher professional-learning needs, and technology-use environments may differ across secondary school levels.

7.3 Future Research

Future research could extend the present study in several directions. First, longitudinal designs would provide stronger evidence regarding how principals' technology leadership and TPD evolve over time and across different stages of school digital transformation. Multi-source designs could further strengthen this

line of research by combining teacher perceptions with principal reports, interviews, observations, and indicators of participation in professional learning.

Second, qualitative and mixed-methods research could examine more closely how the five dimensions of technology leadership are enacted in everyday school practice. In particular, further investigation is needed to understand how Equity and Citizenship Advocacy translates into teachers' actual access to digital resources, professional networks, collaborative learning, and other professional-development opportunities in resource-constrained schools.

Third, future studies could conduct explicit comparisons between junior and senior secondary schools and examine whether school level, resource availability, geographical location, or other contextual characteristics condition the relationship between technology leadership and TPD. Such analyses would provide a more differentiated understanding of whether particular leadership practices are more salient under specific organizational conditions.

Finally, comparative research across different provinces, rural and urban settings, and national contexts would help establish the extent to which the patterns observed in Southwest China are context-specific or transferable to other developing and resource-constrained educational systems. Such research could contribute to a more context-sensitive international understanding of technology leadership and its role in supporting equitable opportunities for teacher professional learning.

7.4 Recommendations

Based on the findings of this study, several recommendations are proposed for school leaders and educational authorities seeking to strengthen TPD in under-resourced schools. First, principals should incorporate equity considerations into school-level technology and professional-development planning. Rather than distributing limited digital resources uniformly without regard to need, schools should identify gaps in teachers' access to devices, connectivity, digital learning resources, and professional-development opportunities and prioritize support for teachers and departments facing the greatest constraints. Regular reviews of participation in technology-supported professional learning can help school leaders identify groups that may otherwise be excluded.

Second, educational authorities should link technology funding more explicitly to TPD. Where budgets are constrained, funding should not be concentrated exclusively on hardware procurement. A defined portion of available digital-development funding should support teacher training, shared digital resources, connectivity, technical assistance, and cross-school professional learning. Priority should be given to investments that can benefit multiple teachers and schools, such as shared platforms, regional digital-resource repositories, school clusters, and online professional-learning networks. Rather than prescribing a universal funding percentage, local authorities should establish transparent budget categories and allocation criteria based on documented school needs, existing infrastructure, and teacher participation gaps.

Third, digital citizenship should be incorporated into professional development for principals and teachers in Guizhou. Training could include practical modules on equitable digital access, data privacy and security, ethical use of digital resources, evaluation of online information, responsible online communication, and the use of emerging technologies, including AI-supported educational tools. These modules should be connected to authentic school and classroom situations rather than delivered only as abstract policy training. For principals, additional emphasis should be placed on identifying inequalities in access and participation and designing school-level responses to them.

Fourth, sustaining equity-oriented initiatives in severely resource-constrained schools requires strategies that do not depend entirely on continuous increases in school funding. Schools can make greater use of shared devices and facilities, peer mentoring, teacher-led workshops, reusable digital resources, cross-school resource sharing, and online professional communities. Educational authorities can facilitate school clusters in which better-supported schools, teacher educators, and local higher education institutions share expertise and professional-learning resources with smaller or more geographically isolated schools. Such approaches cannot replace adequate public investment, but they can help schools use existing resources more collaboratively and sustain professional learning when additional funding is limited.

Finally, implementation should be accompanied by simple and feasible monitoring mechanisms. Schools and local education authorities could periodically review indicators such as teacher participation in professional-development activities, access to digital resources and connectivity, participation in professional networks, and perceived barriers to professional learning. Such monitoring would allow technology-leadership initiatives to be adjusted according to actual patterns of access and participation rather than relying solely on the amount of technology purchased.

Conflict of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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