

Digital literacy and teaching innovation in physical education teachers: a moderated mediation model

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Abstract

Although digital literacy is recognized as a critical competence for primary and secondary physical education teachers in the context of digital transformation in education, the indirect pathways linking digital literacy to teaching innovative behavior remain underexplored. Drawing on Social Cognitive Theory and Conservation of Resources Theory, this study constructed a moderated mediation model to examine the mediating role of teaching self-efficacy and the moderating role of perceived organizational support in this association. A cross-sectional survey was conducted among 984 primary and secondary physical education teachers from several provinces in China, who completed validated self-report scales measuring digital literacy, teaching self-efficacy, teaching innovative behavior, and perceived organizational support. Data were analyzed using SPSS 31.0 and the PROCESS macro. The results indicated that digital literacy was positively associated with teaching innovative behavior. Teaching self-efficacy mediated this relationship, and perceived organizational support positively moderated the association between teaching self-efficacy and teaching innovative behavior, such that the positive association was stronger when perceived organizational support was higher. The index of moderated mediation was significant, revealing that the indirect effect of digital literacy on teaching innovative behavior through teaching self-efficacy was conditional on perceived organizational support. These findings are consistent with a model in which digital literacy, teaching self-efficacy, and organizational support are interlinked resources that may serve as key correlates of innovative teaching practices in physical education. Due to the cross-sectional design, all findings should be interpreted as correlational, not causal.

Introduction

Digital technologies are profoundly reshaping education. UNESCO's Quality Physical Education guidelines stress that physical education (PE) teachers must integrate digital tools into their teaching ¹. In China, the Education Informatization 2.0 Action Plan and the Teacher Digital Literacy standard similarly position digital literacy as central to modernizing education ^{2,3}. For primary and secondary PE teachers, digital literacy is no longer an optional skill but a required competence that is associated with their professional development and teaching innovative behavior ^{4,5}. However, the indirect pathways linking digital literacy to teaching innovative behavior remain underexplored.

Teaching innovative behavior refers to the willingness and ability to introduce novel instructional methods, integrate technology, and adapt to changing educational demands ⁶. Digital literacy may provide teachers with technical skills and digital resources, and these are statistically associated with their capacity to design more engaging lessons ^{7,8}. Teachers' ICT competence is positively associated with teaching quality and innovative practices, as confirmed by a meta-analysis ⁹. For PE teachers, digital tools can support differentiated instruction, video analysis, and student feedback ^{10,11}. Accordingly, the following hypothesis is proposed.

H1

Digital literacy is positively associated with teaching innovative behavior among primary and secondary physical education teachers.

According to social cognitive theory ¹², personal beliefs about one's capabilities, namely self-efficacy, play a central role in translating knowledge into action. Teaching self-efficacy refers to teachers' confidence in

executing teaching tasks and promoting student learning¹³. Digital literacy may serve as a personal cognitive resource that is positively associated with self-efficacy: prior research suggests that teachers proficient with digital tools tend to report higher confidence in managing technology-rich classrooms^{14,15}. In turn, higher self-efficacy has been statistically associated with greater willingness to adopt innovative methods and demonstrate higher teaching innovative behavior in previous research^{16,17}. Therefore, a mediating pathway is hypothesised.

H2

Teaching self-efficacy mediates the association between digital literacy and teaching innovative behavior.

Conservation of resources theory¹⁸ posits that individuals strive to acquire and protect valued resources, and that external resources can interact synergistically with internal resources, a process known as a resource gain spiral. Perceived organizational support (POS) refers to teachers' belief that their school values their contributions and cares about their well-being^{19–21}. POS may be viewed as a critical external resource²². When POS is high, teachers tend to report greater confidence that their innovative attempts will be recognized and supported, which is associated with a stronger positive association between self-efficacy and innovation²³. Conversely, low POS may hinder this translation²⁴. Evidence from other educational studies confirms that perceived organizational support moderates the relationship between self-efficacy and positive work outcomes^{25,26}. Accordingly, a moderating role is proposed.

H3

Perceived organizational support moderates the relationship between teaching self-efficacy and teaching innovative behavior, such that the positive association between self-efficacy and innovation is stronger when POS is higher.

To fill this research gap, drawing on Social Cognitive Theory and Conservation of Resources Theory, the present study constructs a moderated mediation model, as depicted in Fig. 1, to test the mediating role of teaching self-efficacy and the moderating role of perceived organizational support. It was proposed that the indirect association between digital literacy and teaching innovative behavior via teaching self-efficacy is conditional on the level of POS.

H4

Perceived organizational support moderates the indirect association of digital literacy with teaching innovative behavior through teaching self-efficacy, such that the indirect association is larger under higher POS.

Methods

Participants and Procedure

A convenience cluster sampling method was adopted. Given the geographic dispersion of the target population across eastern, central, and western China, and the practical constraints of accessing schools with limited administrative coordination, a fully randomized sampling design was not feasible. To improve representativeness while maintaining feasibility, participants were recruited from primary and secondary

schools across several provinces spanning three major economic regions, with schools selected to reflect urban-rural and socioeconomic diversity.

The target sample size was determined a priori using G*Power 3.1.9.2 ²⁷. The statistical test was set as an F-test within the linear multiple regression framework (fixed model, R² increase). The regression model included three main effect variables (digital literacy, teaching self-efficacy, and perceived organizational support), one interaction term (teaching self-efficacy × perceived organizational support), and five demographic control variables (gender, age, teaching experience, school level, and region). Thus, the total number of predictors in the regression model was 9, with 1 tested predictor (the interaction term). Based on a conservative small effect size, the effect size was set to $f^2 = 0.02$, significance level $\alpha = 0.05$, and statistical power $1 - \beta = 0.95$. The analysis indicated an estimated required total sample size of $N = 652$. Corresponding output parameters were: noncentrality parameter $\lambda = 13.04$, critical $F = 3.86$, numerator $df = 1$, denominator $df = 642$, and actual power = 0.9501.

The sample comprised 577 males (58.6%) and 407 females (41.4%). Age distribution was as follows: ≤30 years (26.0%), 31–40 years (45.5%), and ≥ 41 years (28.5%). Teaching tenure distribution was: ≤5 years (22.9%), 6–10 years (30.0%), 11–20 years (34.5%), and ≥ 21 years (12.7%). In terms of school level, 394 teachers (40.0%) were from primary schools, 315 (32.0%) from junior secondary schools, and 275 (27.9%) from senior secondary schools. Participants came from Eastern China (37.8%), Central China (31.9%), and Western China (30.3%). Detailed demographic characteristics are presented in Table 1.

Informed consent

was obtained online from all participants prior to data collection. They were free to withdraw from the study at any time. This study was reviewed and approved by the Medical Ethics Committee of Wuhan University (Approval No. WHU-LFMD-IRB2025027). All participants were in-service primary and secondary physical education teachers aged 22 years or older; therefore, no parental or guardian consent was required. Participation was voluntary, and all responses were processed anonymously to ensure confidentiality.

Measures

Digital Literacy

Digital literacy was measured using the Digital Literacy Scale adapted from ²⁸. The scale consists of 10 items measuring three dimensions: digital tool operation, information evaluation, and digital content creation. A sample item is "I have confidence in my ability to search for and evaluate information obtained from the Internet." All items were rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating greater digital literacy. In the present study, the Cronbach's α for the scale was 0.93, indicating excellent internal consistency.

Teaching Self-Efficacy

Teaching self-efficacy was measured using the short form of the Teachers' Sense of Efficacy Scale ¹³. The scale comprises 12 items across three dimensions: efficacy for classroom management, student engagement, and

instructional strategies. A sample item is "How much can you do to get students to believe they can do well in physical education class?" Items are rated on a 9-point scale ranging from 1 (nothing) to 9 (a great deal), with higher scores indicating greater teaching self-efficacy. In the present study, the Cronbach's α for the scale was 0.91, indicating good reliability.

Teaching Innovative Behavior

Teaching innovative behavior was measured using the Teachers' Innovative Behavior Scale developed by ²⁹. The scale includes 17 items covering four dimensions: exploring opportunities, generating ideas, promoting ideas, and implementing ideas. A sample item is "I try to introduce new teaching methods to address instructional problems." All items were rated on a 5-point Likert scale ranging from 1 (never) to 5 (always), with higher scores indicating more frequent teaching innovative behaviors. In the present study, the Cronbach's α for the scale was 0.94, indicating excellent internal consistency.

Perceived Organizational Support

Perceived organizational support was measured using the Survey of Perceived Organizational Support adapted from ³⁰. The scale consists of 14 items assessing teachers' beliefs about whether their school values their contributions and cares about their well-being. A sample item is "My school considers my goals and values when making important decisions." All items were rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating greater perceived organizational support. In the present study, the Cronbach's α for the scale was 0.97, indicating excellent internal consistency.

Data Analysis

All statistical analyses were performed using SPSS 31 (IBM Corp., Armonk, NY, USA). Descriptive statistics and Pearson correlations were computed to examine the means, standard deviations, and bivariate relationships among the study variables. Common method bias was assessed using Harman's single-factor test ³¹.

A moderated mediation model was tested using PROCESS macro Model 14 for SPSS ³², with digital literacy as the independent variable, teaching innovative behavior as the dependent variable, teaching self-efficacy as the mediator, and perceived organizational support as the moderator. Gender, age, teaching tenure, school level (primary, junior secondary, or senior secondary), and region (eastern, central, or western China) were included as control variables. PROCESS Model 1 was first used to examine the moderating association of POS on the TSE → TIB path, which served as a preliminary step for the subsequent moderated mediation analysis.

Prior to hypothesis testing, the normality of the regression residuals was examined (see Supplementary Figure S1). All continuous variables were mean-centered to reduce multicollinearity and facilitate interpretation of interaction effects ³³. Complete regression coefficients for all control variables are presented in Supplementary Table S3.

Results

Common Method Bias

Following established recommendations³¹, Harman's single-factor test was conducted to assess common method bias. All items from the key variables (digital literacy, teaching self-efficacy, teaching innovative behavior, and perceived organizational support) were entered into an unrotated principal component factor analysis. The results indicated that 14 factors had eigenvalues greater than 1, and the first unrotated factor accounted for 34.61% of the total variance, well below the 40% threshold. This result suggests that no single factor accounted for the majority of covariance among the items. However, given the known limitations of Harman's single-factor test and the self-report, cross-sectional nature of the data, common method variance cannot be fully ruled out and may have inflated the observed associations. Therefore, the findings should be interpreted with caution.

Descriptive Statistics and Correlations

Table 2 presents the means, standard deviations, and Pearson correlations for the main variables. Digital literacy was positively correlated with teaching self-efficacy ($r = 0.439, p < 0.001$), teaching innovative behavior ($r = 0.365, p < 0.001$), and perceived organizational support ($r = 0.542, p < 0.001$). Teaching self-efficacy was positively correlated with teaching innovative behavior ($r = 0.271, p < 0.001$) and perceived organizational support ($r = 0.376, p < 0.001$). Perceived organizational support was also positively correlated with teaching innovative behavior ($r = 0.336, p < 0.001$). These correlations provide initial support for the hypothesized relationships. Of note, the mean score for teaching innovative behavior was 2.40 (SD = 0.75), which is below the theoretical midpoint of the 5-point scale, indicating a relatively low self-reported frequency of innovative practices among the participating PE teachers. However, the standard deviation (0.75) suggests sufficient variability in the data to support subsequent regression analyses. To further verify the normality assumption of the regression residuals, the Normal Q-Q Plot and Detrended Normal Q-Q Plot of the unstandardized residuals were visually inspected (see Supplementary Figure S1). The Q-Q plot showed that the residuals predominantly aligned along the diagonal reference line, with only minor deviations at the tails. Given the large sample size ($N = 984$) and the overall pattern of the plots, the normality assumption for the regression residuals was considered adequately met³⁴.

Confirmatory Factor Analysis

To examine the construct validity of the scales, confirmatory factor analysis (CFA) was conducted on digital literacy, teaching self-efficacy, teaching innovative behavior, and perceived organizational support. The model fit indices are presented in Table 3. The four-factor model showed acceptable fit to the data: $\chi^2/df = 3.510$, CFI = 0.915, TLI = 0.912, RMSEA = 0.051, 90% CI [0.049, 0.052], PCLOSE = 0.289, HOELTER = 299, supporting the distinctiveness of the four constructs.

Subsequently, convergent and discriminant validity were examined. As shown in Table 4, the composite reliabilities (CR) for all constructs ranged from 0.926 to 0.974, exceeding the 0.70 threshold. The average variance extracted (AVE) values ranged from 0.484 to 0.731; although the AVE for teaching innovative behavior was slightly below 0.50, its CR was substantially above 0.70, and all other AVE values exceeded 0.50, indicating acceptable convergent validity³⁵. This is consistent with the view that AVE is a conservative measure of convergent validity³⁶, and that composite reliability above 0.70 with significant factor loadings provides evidence of adequate convergent validity.

For discriminant validity, Table 5 presents the Fornell-Larcker criterion. The square root of each construct's AVE (bold diagonal values) was greater than its correlations with other constructs, confirming satisfactory discriminant validity. Moreover, the HTMT values (see Supplementary Table S1) for $DL \leftrightarrow TSE$ and $DL \leftrightarrow POS$ were 0.858, which are well below the widely accepted 0.90 threshold³⁷, further supporting adequate discriminant validity. Taken together, these results indicate that the four constructs are empirically distinguishable, despite their theoretical relatedness as facets of teachers' professional capabilities.

To assess potential multicollinearity, we examined the variance inflation factors (VIFs) for all predictors in the full regression model, including the interaction term (see Supplementary Table S4). The VIF values for all predictors ranged from 1.004 to 1.585, well below the conservative threshold of 3.0³⁸, indicating that multicollinearity did not unduly influence the regression estimates.

Moderating Effects

Following the analytical strategy outlined in Section 2.3, a regression model was run using PROCESS macro Model 1³², with 5,000 bootstrap samples, controlling for gender, age, teaching tenure, school level, and region. The results are summarized in Table 6. Simple slope estimates at different levels of POS are presented in Table 7. The patterns of significance for the hypothesized path remained unchanged after including school level and region as additional covariates.

The interaction between TSE and POS was significantly associated with teaching innovative behavior ($B = 0.047$, $p = 0.002$, 95% CI [0.017, 0.076]). Simple slope analysis revealed that the positive association between TSE and TIB was significant at all levels of POS, although the association was weaker at low POS ($B = 0.050$, $p = 0.032$), and stronger at mean POS ($B = 0.103$, $p < 0.001$) and high POS ($B = 0.157$, $p < 0.001$), as shown in Fig. 2.

Moderated Mediation

The moderated mediation model was further tested (PROCESS Model 14) in which perceived organizational support moderates the second stage of the mediation (the path from teaching self-efficacy to teaching innovative behavior), controlling for gender, age, teaching tenure, school level, and geographic region. The results are displayed in Table 8.

Digital literacy was strongly positively associated with teaching self-efficacy ($a = 0.736$, $p < 0.001$). The interaction term ($TSE \times POS$) was significantly associated with teaching innovative behavior (coefficient = 0.057, $p < 0.001$), confirming that POS moderates the $TSE \rightarrow TIB$ relationship.

The index of moderated mediation was 0.042, 95% bootstrap CI [0.019, 0.066], indicating that the indirect association of digital literacy on teaching innovative behavior through teaching self-efficacy varies as a function of POS.

Conditional indirect effects showed that the indirect pathway was significant at mean POS (effect = 0.057, 95% Boot CI [0.026, 0.088]) and high POS (effect = 0.105, 95% Boot CI [0.054, 0.154]), but not at low POS (effect = -0.006, 95% Boot CI [-0.038, 0.027]). To precisely identify the activation threshold, Johnson-Neyman analysis revealed that the conditional indirect effect was statistically significant only when the centered value of POS exceeded -0.5121, corresponding to an uncentered POS score of approximately 2.81 on the 5-point scale. Given that the sample mean for POS was 3.32 ($SD = 1.13$), this threshold lies slightly below the theoretical midpoint

(3.0) of the scale, suggesting that the indirect effect becomes significant at relatively moderate levels of perceived organizational support.

Discussion

Guided by Social Cognitive Theory and Conservation of Resources theory, this study constructed a moderated mediation model to examine how digital literacy relates to teaching innovative behavior among primary and secondary physical education teachers, with a focus on the mediating role of teaching self-efficacy and the moderating role of perceived organizational support. The results showed that digital literacy was positively associated with teaching innovative behavior, that teaching self-efficacy mediated this relationship, that perceived organizational support positively moderated the association between teaching self-efficacy and teaching innovative behavior, and that the moderated mediation effect was present.

Before discussing individual hypotheses, it is important to contextualize the overall findings. The explained variance ($R^2 = 0.15\text{--}0.17$) indicates that the three core variables—digital literacy, teaching self-efficacy, and perceived organizational support—collectively account for a modest proportion of the variance in teaching innovative behavior. This suggests that while the hypothesized associations are statistically significant, they represent only one piece of a more complex picture. The low mean score for teaching innovative behavior ($M = 2.40$) further implies that, in the current sample, PE teachers generally report low levels of pedagogical innovation, which may reflect broader systemic constraints specific to PE teachers, such as the historical marginalization of physical education within the school curriculum, insufficient infrastructural and equipment support, and limited access to continuous professional development tailored to digital pedagogy. Future research should explore these additional structural and contextual factors.

It was found that digital literacy was positively associated with teaching innovative behavior among primary and secondary physical education teachers. This result aligns with the meta-analytic conclusion of ⁹ that teachers' ICT competence is positively correlated with teaching quality and innovative practices. According to Social Cognitive Theory, teachers with higher digital literacy tend to report stronger abilities to acquire and process instructional information and design varied learning activities, and this capability tends to co-occur with their willingness and ability to innovate ^{39,40}. For physical education teachers, digital tools such as motion analysis software, wearable devices, and online platforms have the potential to transcend the traditional time-space constraints of physical education, offering possibilities for personalized feedback and real-time instruction. Consistent with this notion, the present findings show that these applications are positively associated with self-reported teaching innovative behavior. ^{10,41,42}. Consequently, digital literacy appears to be a relevant competency warranting attention in physical education teacher professional development, although the correlational nature of this study precludes causal claims regarding its effectiveness. Nonetheless, these findings provide an empirical basis for future experimental or longitudinal research to further examine the causal pathways through which digital literacy may be associated with innovative teaching practices.

A second finding is that teaching self-efficacy mediates the relationship between digital literacy and teaching innovative behavior. This result is consistent with Social Cognitive Theory, which posits that external skills are associated with behavior through internal self-beliefs ¹². In the present context, digital literacy serves as the external skill, teaching innovative behavior as the outcome, and teaching self-efficacy as the internal belief system that bridges them ^{43–45}. Teachers with higher digital literacy in the present sample tended to report

feeling more in control of technology, and this sense of control was positively associated with their confidence in completing teaching tasks ^{46,47}. Teachers' teaching beliefs are positively associated with their willingness to try new methods and with persistence in the face of difficulties ^{16,48}. This mediation pattern is similar to that reported by ⁴⁹ in the context of teaching internships, suggesting that self-efficacy is one plausible pathway that may help account for the statistical association between external skills and self-reported teaching behavior. Therefore, professional development programs that combine technical skill-building with mastery-based self-efficacy enhancement may consider incorporating self-efficacy enhancement as one of multiple strategies for supporting innovative behavior.

The present study also revealed that perceived organizational support moderates the association between teaching self-efficacy and teaching innovative behavior. Under high perceived organizational support, the positive association between self-efficacy and innovation was stronger, while under low support, this positive association was weaker. This finding is consistent with the resource gain spiral principle of Conservation of Resources theory ¹⁸: perceived organizational support, as an external resource, may work synergistically with internal resources such as self-efficacy, a pattern that could be interpreted as being associated with teachers' investment of effort in innovation and their tolerance of possible setbacks ^{50,51}. This moderating pattern parallels previous research highlighting the synergistic role of external resources ^{24,39}.

This moderating pattern is based on cross-sectional data and does not imply that altering perceived organizational support would causally change the relationship between teaching self-efficacy and teaching innovative behavior.

Taken together, the results are consistent with the hypothesized moderated mediation model, although causal interpretations are precluded by the cross-sectional design. The indirect association between digital literacy and teaching innovative behavior through teaching self-efficacy was stronger and statistically significant at higher levels of perceived organizational support, but non-significant at low support. The index of moderated mediation was 0.042, with a 95% confidence interval of [0.019, 0.066], further supporting the plausibility of this model as a representation of the observed data. This finding echoes the moderated mediation pattern reported by ⁵¹ in teacher innovation research, where an environmental factor moderated the indirect path. From a practical perspective, the observed associations of digital literacy may not be uniform across all contexts. In the present data, the association appears stronger only when schools provide adequate organizational support, suggesting that digital literacy shows a stronger positive association with teaching innovative behavior through enhanced self-efficacy under conditions of higher organizational support. Thus, improving teachers' digital skills without simultaneously strengthening the school support system may not be associated with the expected innovative outcomes.

This study makes three theoretical contributions. First, it integrates Social Cognitive Theory ¹² and Conservation of Resources theory ¹⁸ into a unified moderated mediation framework, offering a novel theoretical lens for understanding how technical skills are associated with teaching practice. While previous studies often used either theory alone ^{13,52}, this work illustrates their complementarity: Social Cognitive Theory explains the pathway linking skills to beliefs to behavior, and Conservation of Resources theory explains how external resources work synergistically with that pathway. Second, by focusing on primary and secondary physical education teachers, the study extends educational technology research to a historically underrepresented group.

Physical education, with its high physical engagement and real-time interaction, is often neglected in the digital transformation discourse ⁴; the findings show that digital literacy is also meaningfully associated with innovation for physical education teachers. Third, the study refines the understanding of where perceived organizational support operates. Previous research has primarily focused on its direct effects ⁵², whereas the findings specify its moderating position in this moderated mediation model: POS positively moderates the second stage of the mediation (TSE → TIB), suggesting that organizational support plays a synergistic role in the association of self-efficacy with innovative teaching behavior.

The findings offer several practical implications for the education and management of primary and secondary physical education teachers. First, given the observed associations, school administrators may consider integrating digital literacy training into regular professional development, extending beyond basic tool operation to include digital instructional design and data-driven decision making ⁴. Second, a supportive organizational climate appears potentially beneficial and could be fostered through adequate technological resources, evaluation systems that encourage constructive experimentation, and peer sharing sessions on digital teaching experiences, as such organizational resources may signal to teachers that their innovative efforts are valued and protected ⁵¹. Third, teacher training could explicitly target self-efficacy enhancement through mastery-based approaches such as workshops, teaching observations, and success case sharing that allow teachers to practice in low-stakes environments and receive positive feedback. However, these suggestions are derived from correlational data and should be tested in future intervention studies ⁴⁰. Fourth, administrators should recognize that, based on correlational evidence, hardware investment or skill training alone may be insufficient; a supportive school culture should be built simultaneously to support the benefits of digital literacy, as organizational support showed a stronger synergistic association between digital competence and pedagogical innovation. Importantly, these practical suggestions are derived from cross-sectional data and should be interpreted as potential areas for future intervention research rather than established causal recommendations

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- Several methodological limitations should be acknowledged when interpreting the present findings. First, the cross-sectional design does not permit causal inference; future research could employ longitudinal or experimental designs to establish temporal precedence between digital literacy and teaching innovative behavior. Second, the reliance on self-report measures may be affected by social desirability bias; future research could incorporate multi-source data such as classroom observations, peer evaluations, or student assessments to triangulate the findings. Third, the relatively modest explained variance ($R^2 = 0.15\text{--}0.17$) suggests that other unmeasured factors—such as leadership style, peer collaboration, school climate, and teacher personality—also contribute substantially to teaching innovative behavior, and should be incorporated in future models. Additionally, the relatively low mean score for teaching innovative behavior ($M = 2.40$) may reflect the current educational reality in China, where PE has historically received less emphasis on pedagogical reform. While this restricted range may have led to conservative effect estimates, the fact that significant associations were detected despite this limitation suggests that the findings are relatively robust. Future research could include teachers from innovation-oriented schools or adopt behavioral observation measures to capture a wider spectrum of innovative practices. Fourth, the convenience cluster sampling method somewhat limits the generalizability of the findings; although efforts were made to recruit participants from multiple provinces across eastern, central, and western China, a probability sampling design would strengthen external validity in future research. Finally, while the Fornell–

Larcker criterion supported discriminant validity, the HTMT values for DL↔TSE and DL↔POS slightly exceeded the 0.85 threshold, and the AVE for TIB was marginally below 0.50, suggesting that the measurement of these constructs could be further refined in future studies. Nevertheless, given that the Fornell–Larcker criterion was fully satisfied and all composite reliabilities were well above 0.70, these measurement issues are unlikely to substantially influence the substantive conclusions of the study.

Conclusion

Based on Social Cognitive Theory and Conservation of Resources theory, this study tested the statistical associations between digital literacy and teaching innovative behavior among primary and secondary physical education teachers, the mediating role of teaching self-efficacy, and the moderating role of perceived organizational support. Analysis of data from 984 in-service physical education teachers showed that digital literacy was positively associated with teaching innovative behavior, that teaching self-efficacy partially mediated this relationship, that perceived organizational support positively moderated the association between teaching self-efficacy and teaching innovative behavior, and that the moderated mediation effect was significant. These findings are consistent with a model in which digital literacy, teaching self-efficacy, and organizational support are interlinked resources that may serve as key correlates of innovative teaching practices in physical education and may inform future causal and intervention studies. However, given the modest effect sizes and cross-sectional design, these implications warrant caution.

Declarations

Conflict of Interest

The authors do not announce any conflicts of interests.

Author Contributions

C.C. contributed to conceptualization, supervision, writing – review and editing, and project administration. S.Z. contributed to conceptualization, data curation, methodology, and writing – original draft. B.Z. contributed to investigation and data curation. J.G. contributed to investigation and methodology. P.G. contributed to investigation and methodology. Y.X. contributed to data curation and formal analysis. L.L. contributed to investigation and data curation. R.L. and T.X. contributed to data curation. All authors approved the final version for publication.

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Data Availability Statement

The anonymised dataset that supports the findings of this study is provided as supplementary material. Other relevant materials may be obtained from the corresponding author upon reasonable request.

10 Ethics statement

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the Medical Ethics Committee of Wuhan University (Approval No. WHU-LFMD-IRB2025027). Informed consent was obtained online from all participants prior to data collection. Participants were informed of the study purpose, procedures, and their right to withdraw at any time without penalty. All data were processed anonymously to ensure confidentiality.

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Tables

Table 1 Demographic characteristics of participants (N = 984)

Characteristic	Category	n	%
Gender	Male	577	58.6
	Female	407	41.4
Age (years)	≤ 30	256	26.0
	31 – 40	448	45.5
	≥ 41	280	28.5
Teaching tenure (years)	≤ 5	225	22.9
	6 – 10	295	30.0
	11 – 20	339	34.5
	≥ 21	125	12.7
School level	Primary school	394	40.0
	Junior secondary school	315	32.0
	Senior secondary school	275	27.9
Region	Eastern China	372	37.8
	Central China	314	31.9
	Western China	298	30.3

Table 2 Descriptive statistics and correlations.

Variable	M	SD	1	2	3	4
1. Digital literacy	3.95	0.78	—			
2. Teaching self-efficacy	6.61	1.31	0.439***	—		
3. Teaching innovative behavior	2.40	0.75	0.365***	0.272***	—	
4. Perceived organizational support	3.32	1.13	0.542***	0.376***	0.336***	—

*** $p < 0.001$.

Table 3. Confirmatory Factor Analysis: Model Fit Indices

Model	χ^2	df	χ^2/df	CFI	TLI	RMSEA	90% CI	PCLOSE	HOELTER
Four-factor model	4629.390	1319	3.510	0.915	0.912	0.051	[0.049, 0.052]	0.289	299
Recommended standards	—	—	< 5	> 0.90	> 0.90	< 0.08	—	> 0.05	> 200

CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = Root Mean Square Error of Approximation; CI = Confidence Interval; PCLOSE = p-value for test of close fit (RMSEA < 0.05); HOELTER = Hoelter's critical N at $\alpha = 0.05$. All factor loadings were significant at $p < 0.001$ (see Supplementary Table S2 for standardized loadings and squared multiple correlations). The four-factor model showed acceptable fit to the data, supporting the distinctiveness of the four constructs: Digital Literacy, Teaching Self-Efficacy, Teaching Innovative Behavior, and Perceived Organizational Support.

Table 4. Convergent Validity and Composite Reliability

Latent Variable	Cronbach's α	CR	AVE
Digital Literacy (DL)	0.93	0.936	0.596
Teaching Self-Efficacy (TSE)	0.91	0.926	0.510
Perceived Organizational Support (POS)	0.97	0.974	0.731
Teaching Innovative Behavior (TIB)	0.94	0.940	0.484

CR = Composite Reliability; AVE = Average Variance Extracted. All CR values exceeded the recommended threshold of 0.70. Although the AVE for TIB was slightly below 0.50, its CR was well above 0.70, and all other AVE values exceeded 0.50, supporting adequate convergent validity.

Table 5. Discriminant Validity: Fornell-Larcker Criterion

Factor	DL	TSE	POS	TIB
DL	0.772			
TSE	0.473	0.714		
POS	0.566	0.397	0.855	
TIB	0.364	0.268	0.330	0.696

Diagonal bold values are the square roots of the AVE. Off-diagonal values are latent factor correlations derived from the confirmatory factor analysis (AMOS). These values differ slightly from the observed variable correlations reported in Table 2 (e.g., DL-POS = 0.566 vs. 0.542), which is expected because latent correlations are disattenuated for measurement error.

Table 6. Moderating Effects of Perceived Organizational Support

Variable	Predictor	B	SE	t	p	95% CI
TIB	TSE	-0.052	0.051	-1.017	0.309	[-0.152, 0.048]
TIB	POS	-0.119	0.099	-1.197	0.232	[-0.313, 0.076]
TIB	TSE $\times$ POS	0.047	0.015	3.082**	0.002	[0.017, 0.076]

$R = 0.39$, $R^2 = 0.15$, $F(8, 975) = 21.31^{***}$; $\Delta R^2 = 0.008$, $\Delta F(1, 975) = 9.50^{**}$ (for the interaction term). TIB = Teaching Innovative Behavior; TSE = Teaching Self-Efficacy; POS = Perceived Organizational Support. $^{**}p < 0.01$; $^{***}p < 0.001$.

Table 7. Simple Slopes at Different Levels of Organizational Support

Model	POS level	Effect	SE	t	p	95% CI
TSE → TIB	Low POS (−1 SD)	0.049	0.023	2.130	0.033	[0.004, 0.095]
TSE → TIB	Mean POS	0.103	0.018	5.636	<0.001	[0.067, 0.139]
TSE → TIB	High POS (+1 SD)	0.157	0.027	5.856	<0.001	[0.104, 0.210]

POS levels are based on mean-centered values. Low POS = mean − 1 SD, high POS = mean + 1 SD.

Table 8. Moderated Mediation Analysis Results

Path or Effect	B	SE	t	p	95% CI
First stage					
DL → TSE	0.736	0.048	15.198	<0.001	[0.641, 0.831]
Second stage					
TSE → TIB	-0.121	0.051	-2.381	0.018	[-0.221, -0.021]
Direct effect					
DL → TIB	0.231	0.035	6.656	<0.001	[0.163, 0.300]
Interaction					
TSE × POS → TIB	0.057	0.015	3.816	<0.001	[0.028, 0.086]
Conditional indirect effects					
Low POS (−1 SD)	-0.006	0.016			[-0.038, 0.027]
Mean POS	0.057	0.016			[0.026, 0.088]
High POS (+1 SD)	0.105	0.025			[0.054, 0.154]
Index of moderated mediation	0.042	0.012			[0.019, 0.065]

Conditional indirect effects and the index of moderated mediation were tested using bias-corrected bootstrap 95% confidence intervals with 5,000 resamples. POS levels are based on mean-centered values. DL = Digital Literacy; TSE = Teaching Self-Efficacy; TIB = Teaching Innovative Behavior; POS = Perceived Organizational Support.

Figures

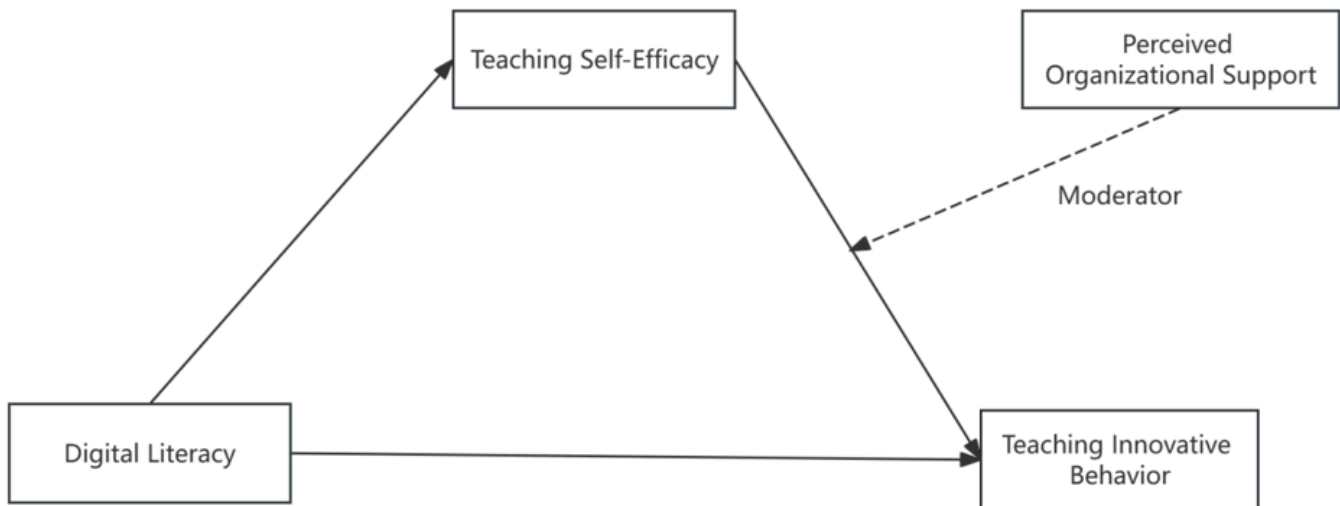


Figure 1

Framework of the proposed moderated mediation model.

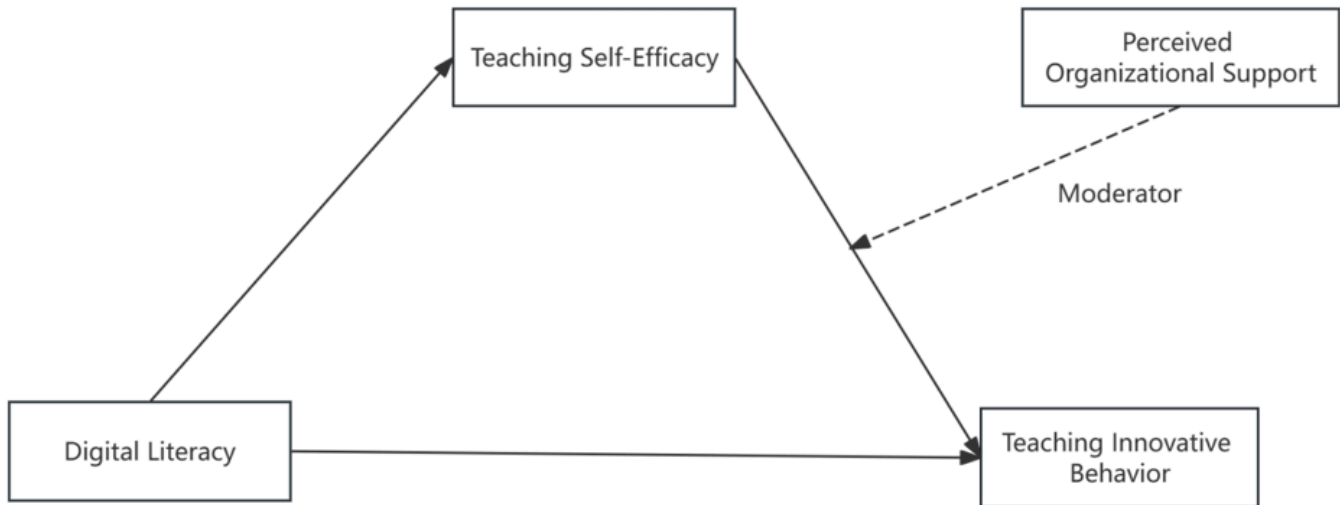


Figure 1

Framework of the proposed moderated mediation model.

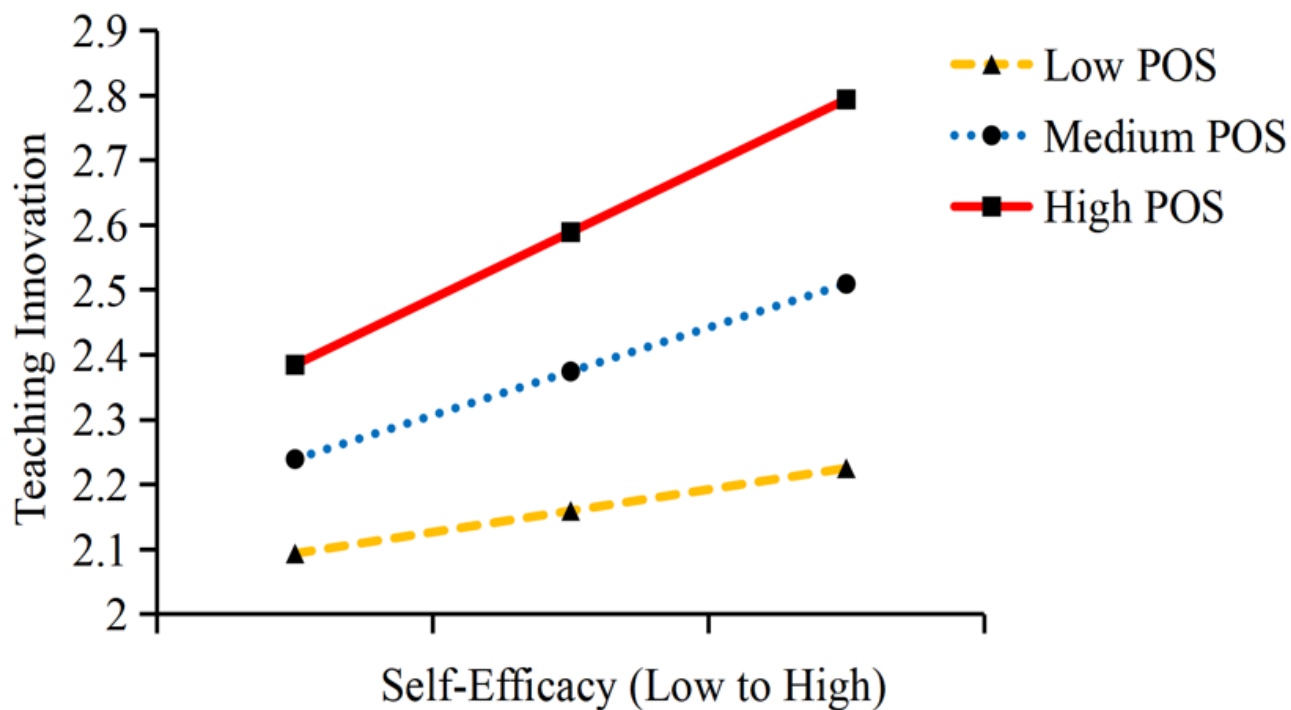


Figure 2

Moderating effect of perceived organizational support (POS) on the relationship between teaching self-efficacy and teaching innovative behavior.

Note. Simple slopes were plotted at three levels of POS: low ($M - 1$ SD), moderate (M), and high ($M + 1$ SD). The interaction term was significant ($B = 0.047$, $p = 0.002$). The positive effect of teaching self-efficacy on teaching innovative behavior was significant at all three levels, but was strongest when POS was high ($B = 0.157$, $p < 0.001$), moderate at mean POS ($B = 0.103$, $p < 0.001$), and weakest at low POS ($B = 0.049$, $p = 0.033$).

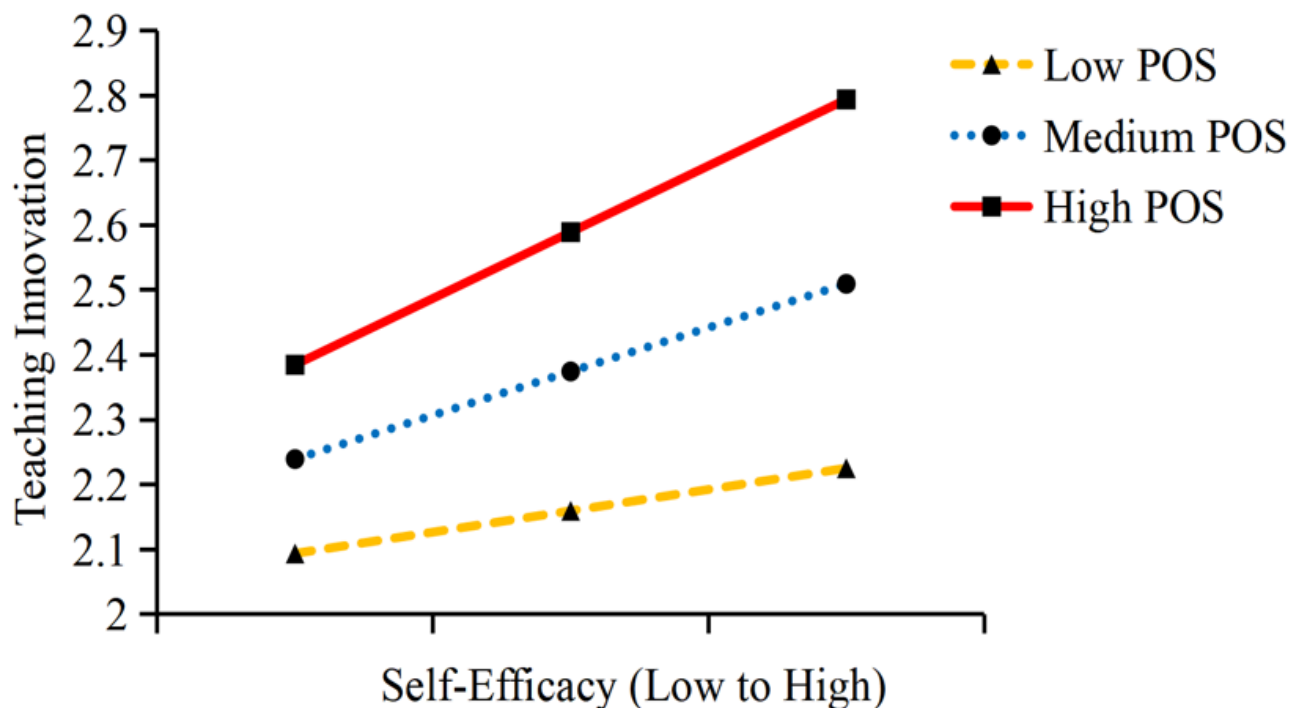


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