

The Mediating Role of Student Engagement in the Relationship Between Teacher Technological Pedagogical Content Knowledge and Physical Performance Among Physical Education Student

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DOI: <https://dx.doi.org/10.47772/IJRISS.2026.100300011>

Received: 06 March 2026; Accepted: 11 March 2026; Published: 24 March 2026

ABSTRACT

In recent years, the physical fitness of university students has declined, prompting China to promote the digital transformation of education. Although the Technological Pedagogical Content Knowledge (TPACK) framework has been shown to improve instructional effectiveness, how teachers' digital competence translates into students' physical performance remains insufficiently understood. This study examined the relationships among teacher TPACK, student engagement, and physical performance among undergraduate physical education (PE) students in China. It also tested the mediating role of student engagement based on the Stimulus–Organism–Response (S–O–R) model, which explains how external stimuli influence internal states and lead to observable outcomes. A cross-sectional survey was conducted between November 2025 and January 2026 with 872 PE undergraduates from four universities in Guangdong Province, China. Teacher TPACK, student engagement, and physical performance were measured using validated instruments. Structural equation modeling (Smart PLS 4) was used to examine both direct and mediating effects. Teacher TPACK significantly predicted student engagement ($\beta = 0.780, p < 0.001$) and physical performance ($\beta = 0.337, p < 0.001$). Student engagement also had a positive effect on physical performance ($\beta = 0.321, p < 0.001$) and partially mediated the relationship between TPACK and physical performance ($\beta = 0.250, p < 0.001$). The model explained 60.8% of the variance in student engagement and 38.6% of the variance in physical performance. Teacher TPACK enhances student engagement and physical performance, supporting the applicability of the S–O–R model in physical education contexts.

Keywords: Physical education, physical performance, student engagement, TPACK

INTRODUCTION

The deterioration of college students' physical health has been an important public health issue worldwide, especially in China. As the National Population Health Science Data Center (2023) reports, the physical fitness level of university students in China, measured in terms of endurance, strength, and flexibility, has been gradually declining [1]. This situation is due to a sedentary lifestyle and the traditional, repetitive methods of teaching physical education (PE), which seem unable to motivate today's digital natives [2], [3]. Hence, the Chinese government has strongly required the reform of PE in higher education institutions. For instance, Guangdong Province issued the "Digital Transformation Action Plan for Education (2023-2027)," calling for intelligent, technology-enhanced teaching in higher education institutions to move from teacher-centered teaching to student-centered learning through information technology to improve physical fitness among students [4].

In this context of digital transformation, the Technology-Pedagogy-Content Knowledge (TPACK) was established as a building block. Mishra and Koehler, TPACK as a special kind of knowledge that teachers need to integrate technology, pedagogy, and subject matter effectively [5]. Unlike other general academic subjects, PE TPACK involves unique applications, such as video analysis to correct movements, wearable devices to monitor heart rates, or gamified applications to track progress [6]. Empirical evidence suggests that higher teacher TPACK develops an inviting, interactive learning environment, which is central to improved instructional effectiveness and the realization of student learning outcomes [7].

Although TPACK is well appreciated [8], two critical gaps emerge from the literature. First, the vast majority of TPACK studies are cognitively oriented toward learning outcomes in subjects such as mathematics or science [9], a quasi-experimental study indicates that the TPACK pedagogical approach demonstrates greater significance than traditional teaching methods, resulting in improved student performance [10] hardly involving psychomotor domains and actual physical performance in real PE. Second, although the impact of teacher TPACK on students has been confirmed. For instance, previous studies have shown that when teachers regard students' engagement as a clear form of feedback [11], it can have an impact on their teaching and learning methods. Just as the TPACK framework adopted by teachers for integrating technology can have a positive effect on students' learning and engagement [12]. The underlying mechanism that projects teachers' digital pedagogical competence onto students' embodied knowledge remains to be further addressed [8]. Teachers' knowledge must arguably influence students through some psychological or behavioral path.

Some findings cited above indicate that physical performance in PE lesson contexts depends on both extrinsic training loads and intrinsic psychological states [13]. For example, previous research analyzed 16 psychological concepts and concluded that different psychological factors exert varying influences on athletic performance [14]. Therefore, mental rehearsal strategies can actively enhance athletic performance, recent research has identified mental training strategies that effectively boost athletic performance [15]. In a sense, student engagement may be one mediating factor [16]. Student engagement has garnered significant attention due to its close relationship with student learning outcomes and the quality of teaching activities [17]. Engagement is a multidimensional construct of three indicators: behavioral, emotional, and cognitive [18]. Active students present indicators of persistence, enthusiasm, and concentration; thus, they can maintain the physically taxing demand to improve athletic performance [19]. Conversely, indicators of low or no engagement are related to stagnation due to the absence of the minimum effort. Hence, teacher TPACK first boosts student engagement and then enhances their physical performance.

To investigate the mediating process, in this study, the Stimulus-Organism-Response (SOR) model was adopted [20]. The SOR model hypothesizes that environmental stimuli trigger an elicit process within the organism of emotional and cognitive states, which then results in a manifest behavior. In this sense, the present study is well-grounded in that a change in students' behavior from mere technology acceptance to engagement needs to take into account the instructional environment created by the teacher. In the present study, teacher TPACK acts as the environmental stimulus, providing a technology-friendly and logical learning environment within which student engagement is activated, i.e., the internal state of the organism. Student physical performance, the behavioral manifestation, occurs when such engagement and effort have been maximally tapped.

This study explored the following questions.

1. What are the correlations between teacher TPACK, student engagement, and physical performance?
2. Does student engagement mediate the relationship between teacher TPACK and physical performance?

METHODS

This study adopted a cross-sectional survey design [21]. Smart PLS-4.0 was used to test the hypothesized model, including measurement model assessment and mediation analysis. This stage design ensured both structural clarity and rigorous hypothesis testing, thereby providing a comprehensive evaluation of the proposed model. This study focuses on undergraduate students in PE, with data gathered from four universities in Guangdong Province, China (November 2025–January 2026).

Research Population

The subjects of this study were undergraduate students from universities, and their major was PE. Table 1 outlines the participant profile, comprising 872 PE undergraduates. The sample reflected a balanced gender distribution (Females: 50.34%; Males: 49.66%) and was predominantly composed of students aged 18–22 (83.03%). In terms of university distribution, University 1 has the highest proportion at 35.32%, while University 3 and University 4 have similar proportions at 26.83% and 27.52%, respectively, and University 2 has the lowest proportion at 10.33%. The distribution of these four universities is both balanced and representative. In summary, this sample demonstrates diversity and representativeness across gender, age, and university background.

TABLE 1. DEMOGRAPHIC INFORMATION (N=872)

Name	Items	Frequency	percentage (%)	Cumulative percentage (%)
Gender	Female	439	50.34	50.34
	Male	433	49.66	100.00
Age	18.0	138	15.83	15.83
	19.0	144	16.51	32.34
	20.0	162	18.58	50.92
	21.0	164	18.81	69.72
	22.0	116	13.30	83.03
	23.0	92	10.55	93.58
	24.0	41	4.70	98.28
	25.0	15	1.72	100.00
College	University 1	308	35.32	35.32
	University 2	90	10.33	45.64
	University 3	234	26.83	72.48
	University 4	240	27.52	100.00

Sampling Strategy

This study used a proportional stratified random sampling method [22], and the university served as the stratification factor. The questionnaires were distributed through stratified random sampling. The number of participants from each university was determined by the university’s proportion of its total student population. Each class within a university was randomly selected, and then the questionnaires were distributed by designated personnel. A total of 1060 questionnaires were distributed. Among them, 960 questionnaires were returned, with a recovery rate of 90.6%. After data screening using SPSS 29, 88 questionnaires were deleted due to incomplete responses or logical errors. The final sample included 872 valid questionnaires.

Instrument

This research instrument consists of 4 parts, each containing questions. Part A is demographic information. Part B is teachers TPACK. Part C is the student engagement scale. Part D is the students physical performance. The researcher adjusted the existing questionnaire to ensure the data and to ensure the questionnaire could answer all the research questions. In this study, demographic information of each respondent will be collected, including 3 items: age, gender (1 is male or 2 is female) and institution.

To assess the TPACK competence of university PE teachers, this study will use the Pre-service Teacher TPACK.xs scale [23]. Each of these 7 scales consists of 4 items. Assessment relied on a five-point Likert-type instrument comprising 28 items, with responses anchored from strongly disagree (1) to strongly agree (5).

Student engagement included behavioral, emotional, and cognitive dimensions. Behavioral and emotional engagement were measured using 10 items, adapted from the Engagement vs. Disaffection with Learning Survey [24]. While cognitive engagement was evaluated using 8 items, it was derived from the Metacognitive Strategies Questionnaire [25]. Assessment relied on a five-point Likert-type instrument comprising 18 items, with

responses anchored from strongly disagree (1) to strongly agree (5).

When assessing physical performance, researchers will adopt different assessment methods for different professional sports programs. Since the subjects of this study were students majoring in sports, the method of measuring student physical performance was based on the “Physical Health Test for Chinese College Students”. This test covers all aspects of physical fitness. For example, endurance, speed, and strength. Assessment relied on a 7-item, 5-point Likert-type instrument, with responses anchored from strongly disagree (1) to strongly agree (5).

Ethical

The Ethics Review Committee of Guangdong University of Science and Technology approved this study (Approval No. GK 2025-1017). We followed all national and institutional ethical standards for human research. All participants provided informed consent digitally and understood they could withdraw at any time without consequences. We protected their privacy and ensured data remained confidential and secure throughout the study.

RESULTS

Convergent Validity and Reliability

To assess the internal consistency of the constructs, this study employed Cronbach’s Alpha and Composite Reliability (CR) as indicators of internal consistency. Cronbach’s Alpha and CR values should be greater than 0.70 (Hair et al., 2019). Cronbach’s Alpha values of all constructs ranged from 0.866 to 0.940. CR values ranged from 0.909 to 0.950 (Table 2). All the values were far above the recommended threshold of 0.70, and even exceeded 0.80. This indicates that the scale has extremely high internal consistency reliability.

Convergent Validity is evaluated by the Average Variance Extracted (AVE) measure. According to the criteria set out in [26], the AVE should be greater than 0.50, indicating that the latent variables explain more than 50% of the variance in their indicators. The results of the data analysis show that the AVE values for all constructs range from 0.636 to 0.758, all of which exceed the critical value of 0.50. This indicates that all constructs in this study have good convergent validity.

Discriminant Validity

TABLE 2. CONVERGENT VALIDITY AND RELIABILITY OF CONSTRUCTS.			
Factor	Cronbach’s alpha	CR	AVE
BE	0.917	0.935	0.706
CE	0.940	0.950	0.703
EE	0.887	0.922	0.747
CK	0.866	0.909	0.713
PK	0.875	0.914	0.727
TK	0.884	0.920	0.741
PCK	0.894	0.926	0.758
TCK	0.884	0.920	0.743
TPK	0.884	0.920	0.742
TPCK	0.883	0.919	0.740
PP	0.905	0.924	0.636

This study employed the Fornell-Larcker criterion to assess discriminant validity. When the square root of the AVE of a certain construct is greater than the correlation coefficient between that construct and all other constructs in the model, discriminant validity can be established [27].

Discriminant validity was further substantiated through the Fornell-Larcker analysis (Table 3 in Appendixes). Results exhibited that the square roots of the AVEs (0.798 to 0.871) were superior to the highest inter-construct correlation value of 0.492. Since the variance extracted by each construct was greater than the variance shared with other constructs, sufficient construct independence was verified.

Structural Model

Path Coefficients

Teacher TPACK had a highly significant and positive impact on student engagement ($\beta = 0.780$, $t = 67.113$, $p < 0.001$). Additionally, teacher TPACK also exerted a significant direct positive effect on physical performance ($\beta = 0.337$, $t = 7.697$, $p < 0.001$). Student engagement was a significant predictor of physical performance ($\beta = 0.321$, $t = 7.106$, $p < 0.001$). These findings strongly support all the direct hypotheses proposed in this study (Table 4 in appendixes). To examine the mediating role of student engagement, this study analyzed specific indirect effects. The results indicated that student engagement played a significant mediating role between teacher TPACK and physical performance ($\beta = 0.250$, $t = 7.033$, $p < 0.001$). Given that the direct effect of teacher TPACK on physical performance (0.337) and the indirect effect (0.250) were both significant and in the same direction. This suggests the presence of complementary partial mediation. This means that teacher TPACK not only directly improved student physical performance but also indirectly enhanced it through increased student engagement.

Explanatory Power and Predictive Relevance

To assess the quality of the structural model, this study examined the coefficient of determination (R^2) and the Stone-Geisser (Q^2) value. The analysis results are summarized in Table 6 (in appendixes).

The R^2 value measures the proportion of the endogenous construct's variance that is explained by the exogenous construct. When the R^2 values are 0.67, 0.33, and 0.19, respectively, they represent substantial, moderate, and weak explanatory power, respectively [28].

This model explains 60.8% of the variance in student engagement ($R^2 = 0.608$), indicating moderate to substantial explanatory power. Additionally, the model explains 38.6% of the variance in physical performance ($R^2 = 0.386$), indicating moderate explanatory power (Table 6 in appendixes). These results suggest that teacher TPACK is the main predictor of student engagement and jointly explains physical performance.

This study also evaluated the model's predictive performance using the Q^2 value. When the Q^2 value is greater than 0, it indicates that the model has predictive validity for the specific endogenous construct [28].

The results show that the values of student engagement ($Q^2 = 0.344$) and physical performance ($Q^2 = 0.607$) are both well above 0 (Table 5). Specifically, the Q^2 value of student engagement indicates a moderate degree of predictive correlation, while the high Q^2 value of physical performance indicates that the model has an extremely strong predictive correlation for this construct.

Effect Size Analysis

In addition to assessing the significance of the path coefficients, this study calculated the effect size (f^2) to evaluate the extent to which the exogenous constructs influence the endogenous constructs. The f^2 value measures the change in f^2 when a specific exogenous construct is removed from the model. The f^2 values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively [29]. Table 6 showed the f^2 values of the direct relationships in the structural model. The results indicated that teacher TPACK had a substantial and large effect on student engagement ($f^2 = 1.551$). In terms of physical performance, both teacher TPACK ($f^2 = 0.073$) and student engagement ($f^2 = 0.066$) showed small effects. Although these effects are classified as small, they all exceed the minimum threshold of 0.02, indicating that these two constructs have made meaningful contributions to the variability in physical performance, although their direct influence is relatively smaller than their impact on engagement.

Figure 1 (in appendixes) showed the structural path estimates. It showed the direct effect of teacher TPACK on student physical performance. It also showed the direct effects of teacher TPACK and student engagement on student physical performance. The figure showed the higher-order structure of teacher TPACK and student engagement. These constructs are formed by their underlying dimensions.

DISCUSSION

This study involves the structural relationship between teacher TPACK, student engagement, and physical performance and further tests student engagement as a mediator in the relationship between teacher TPACK and physical performance. The results obtained are in line with the theoretical model proposed above.

The research results indicate that teachers' TPACK skills have a significant and positive impact on students' physical performance, which is consistent with previous studies that emphasized the value of integrating digital teaching methods in the teaching of sports and health-related fields [30]-[31]. Importantly, this study expands the existing discussions and proves that the influence of digital technology on physical performance is not inherently harmful or negative. On the contrary, under the guidance of teachers with high TPACK levels, digital tools such as motion capture applications, wearable devices, and video feedback systems can be effectively used in teaching, thereby improving the accuracy of training and learning efficiency. Through providing personalized feedback and biomechanical corrections, technology-supported teaching can help students conduct more scientific and effective practice, thereby directly transforming teaching quality into an improvement in physical performance.

The findings of this study further suggest that teacher TPACK is among the most important determinants of student engagement, emphasizing the most appropriate integrated use of technology, pedagogy, and content [32]-[33]. While traditional PE teaching often relies on mechanical training through repetitive drills, TPACK teachers possess many skills to create a learning environment where the technology's advantages are integrated with pedagogical aims to turn monotonous, mindless activities into engaging, meaningful learning experiences. From such an incentive design perspective, these kinds of environments bridge the gaps between students' expectations of heuristic learning and classroom teaching practices, deepening their motivation, immersion, and active participation.

Findings also provide validity for the view of student engagement as a salient antecedent to levels of physical performance (Hughes et al., 2008; Steinmayr et al., 2014). Where engagement has been previously established as a salient precursor to academic achievement, the present findings extend its role within PE to include both psychological involvement and the practice of physio-activities [34]-[35]. Behavioral engagement, then, serves to maximize effective practice time and improve the quality of repetitions, both prerequisites for physical adaptation and the development of a skill. In turn, cognitive engagement underpins the attention required in executing movements, monitoring performance, and correcting errors so that motor learning and deliberate practice can occur. Thus, engagement serves as a psychological state in which learning occurs and a condition through which physical fitness and sport-related abilities are gained or developed.

The mediating role of student engagement is explicable within the SOR model [20]. The first step outside direct influence on learning outcomes by teacher TPACK is via the internal learning state of students, the latter acting as a stimulus to instruction. Student engagement then is the mediating process through which instructional design and the integration of technology are transmuted into observable improvements in performance. It follows that technology-enhanced PE will not just emerge as a function of teachers' digital competencies but also be dependent on the active involvement of students in their learning activities.

CONCLUSION

This study explored the relationship between teacher TPACK, student engagement, and physical performance in university physical education classes while also verifying the mediating role of student engagement. The study found that teacher TPACK was positively related to student engagement and physical performance. Therefore, student engagement becomes an important psychological mechanism in understanding how teacher pedagogical

competence translates into physical performance outcomes.

This has broadened the use of the TPACK framework from traditional cognitive learning outcomes into psychomotor learning contexts and has further evidence to show the framework's power for physical education. Teacher TPACK can, therefore, be considered a pedagogical stimulus within the SOR model that elicits student engagement (organism) and affects physical performance (response). This further provides a theoretical justification for how digital pedagogical competence contributes to processes of developing physical skills.

From a practical point of view, enhancement of physical education teachers' TPACK through professional development programs should lead to greater involvement in and better development of students' physical performance. Properly integrating digital technology tools into the design of physical education instruction will only help motivate students to learn, participate actively in classes, and become better at self-directed learning.

This study has some limitations. The first concerns the cross-sectional design, evidencing limitations in inferring causal relationships among the variables. Second, self-report may produce common method bias. Finally, the sample is restricted to universities in China; thus, further validation is needed concerning the external validity of the findings. Future studies may adopt longitudinal or experimental designs and collect samples across a wider range of cultural and educational contexts to further validate the theoretical relationships proposed here.

Limitations

Despite the theoretical and practical implications of this study, several limitations must be acknowledged when interpreting the findings.

First, this study employed a cross-sectional design, which captures data at a single point in time. While the structural equation modeling (SEM) provided statistical support for the hypothesized relationships based on the S-O-R model, this design precludes the ability to draw strict causal inferences regarding how teacher TPACK evolves to influence student engagement over time. Future research should adopt longitudinal designs or quasi-experimental interventions to rigorously track the dynamic causal effects of technology integration on student physical outcomes.

Second, the measurement of teacher TPACK relied exclusively on students' perceptions rather than teachers' self-assessments or objective observations. While student perception is a valid indicator of teaching effectiveness, relying on a single data source for both independent and dependent variables may introduce common method bias (CMV), where students' general attitude toward a teacher influences their specific ratings. Future studies could employ a multi-informant approach, collecting dyadic data from both teachers and students to obtain a more comprehensive and objective evaluation of TPACK.

Third, the sample was drawn specifically from universities in China. The findings, therefore, reflect the specific educational policies, cultural context, and centralized PE curriculum characteristic of this region. Consequently, caution should be exercised when generalizing these results to other educational stages (e.g., K-12) or Western cultural contexts where teaching autonomy and student demographics may differ. Future research should aim for a broader, cross-cultural sample to validate the robustness of the proposed model globally.

Finally, while this study focused on the impact of teacher knowledge and student engagement, physical performance is a complex trait influenced by multiple factors, such as students' baseline physical fitness, genetics, and extracurricular physical activities, which were not fully controlled for in this study. Future research could incorporate these control variables or use objective metrics (e.g., wearable device data) alongside self-reports to measure physical performance more precisely.

ACKNOWLEDGMENT

The authors express their gratitude to all the students who participated in this research, and also extend their thanks to all the faculty members who assisted in data collection through the school's communication channels.

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APPENDIXES

TABLE 3. FORNELL-LARCKER

	BE	CE	CK	EE	PCK	PK	PP	TCK	TK	TPCK	TPK
BE	0.840										
CE	0.470	0.839									
CK	0.422	0.44	0.844								
EE	0.477	0.471	0.406	0.864							
PCK	0.448	0.475	0.399	0.449	0.871						
PK	0.442	0.486	0.433	0.415	0.414	0.853					
PP	0.484	0.492	0.427	0.428	0.417	0.403	0.798				
TCK	0.473	0.463	0.387	0.413	0.418	0.402	0.383	0.862			
TK	0.443	0.466	0.366	0.446	0.465	0.440	0.425	0.432	0.861		
TPCK	0.417	0.435	0.447	0.407	0.426	0.381	0.436	0.435	0.422	0.860	
TPK	0.431	0.479	0.360	0.444	0.433	0.380	0.412	0.415	0.422	0.406	0.861

TABLE 4. Path Coefficients

Relationship	Beta	T	P
Direct Effects			
Teacher TPACK -> Physical Performance	0.337	7.697	<0.001
Teacher TPACK -> Student Engagement	0.780	67.113	<0.001
Student Engagement -> Physical Performance	0.321	7.106	<0.001
Indirect Effect			
Teacher TPACK -> Student Engagement -> Physical Performance	0.250	7.033	<0.001

TABLE 5. Results of The Model Explanatory Power Test

	R ²	Q ²
Student Engagement	0.608	0.344
Physical Performance	0.386	0.607

TABLE 6. Effect Size Estimates For Direct Effects

	f ²
SE -> PP	0.066
TPACK -> SE	1.551
TPACK -> PP	0.073

