Gamified Learning in Higher Vocational Physical Education: A Four-Group Randomized Controlled Trial

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Abstract: *Background:* Vocational college students represent an underserved demographic in physical education (PE) research, often characterized by lower baseline self-efficacy and elevated psychological distress compared to university peers. While gamification is a promising motivational strategy, existing studies have largely neglected vocational settings and rely heavily on pretest-posttest designs, which fail to control for measurement reactivity. *Methods:* To address these gaps, a Solomon four-group randomized controlled trial was conducted with 200 vocational students (mean age = 19.5 years). Participants were randomly assigned to one of four conditions: gamified PE with pretest, gamified PE without pretest, traditional PE with pretest, or traditional PE without pretest. The 16-week intervention incorporated Self-Determination Theory (SDT) principles (points, leaderboards, leveling) via a custom mobile application. *Results:* Validation of the Solomon design confirmed no pretest sensitization effects ($p > 0.05$). The gamified intervention produced large, robust effects on Learning Motivation ($d = 0.98$) and significantly improved locomotor-based physical fitness, specifically cardiovascular endurance ($p = 0.002$) and sprint speed ($p = 0.002$). However, muscular strength (pull-ups/sit-ups) and BMI showed no significant changes ($p > 0.05$), indicating training specificity. Regarding mental health, perceived stress was significantly reduced ($d = 0.59$), whereas anxiety and depression scores remained unchanged. Mediation analysis identified competence satisfaction ($\beta = 0.853$) as the singular dominant driver of motivation, explaining 43% of the variance, while autonomy played a negligible role. *Conclusions:* Structured gamification is a highly effective pedagogical strategy for enhancing engagement and cardiorespiratory health in vocational PE. However, the lack of improvement in upper-body strength suggests that future interventions must adopt a "hybrid" design that explicitly gamifies resistance-based mechanics to ensure holistic physical development.

Keywords: Gamification; Physical Education; Vocational Education; Self-Determination Theory; Mental Health; Solomon Four-Group Design

INTRODUCTION

Physical education (PE) faces ongoing challenges worldwide, including declining student engagement, reduced physical fitness (PF), and increased mental health (MH) concerns [1,2]. Global surveillance data indicates that over 80% of adolescents fail to meet recommended physical activity guidelines [3]. Traditional teacher-centered instructional approaches have shown limited effectiveness in generating sustained motivation, particularly among late adolescents and emerging adults [4,5].

These challenges are particularly pronounced within vocational education settings. In China, vocational institutions enroll over 10 million students annually, representing 53% of higher education enrollment [6]. Unlike academic university peers, vocational students often experience lower athletic self-efficacy and perceive curriculum as disconnected from their career goals [7,8]. Additionally, research suggests that vocational students may experience lower general self-efficacy due to educational tracking processes [9].

The Chinese educational context presents unique challenges. Students enrolled in vocational colleges through the entrance examination system may develop reduced academic self-confidence, which can generalize to other domains including PE [10]. Recent research from vocational colleges confirms that psychological factors significantly influence the relationship between PE participation and PF outcomes [11]. Only 30.9% of vocational students meet moderate-to-vigorous physical activity standards, with this deficit correlated with higher depression rates [12].

Self-Determination Theory (SDT) provides a framework for understanding motivation in educational contexts. SDT posits that high-quality motivation depends on satisfaction of three basic psychological needs: autonomy, competence, and relatedness [13,14]. Gamification, defined as the application of game design elements in non-game contexts [15], aligns with these needs through mechanisms such as progressive point systems (competence) and collaborative team structures (relatedness) [2,16].

Gamification operates through key elements including points, badges, and leaderboards, which correspond to SDT constructs [17]. Points provide real-time feedback quantifying effort, thereby supporting competence needs. Badges recognize skill mastery independent of peer comparisons. Team-based leaderboards can foster relatedness through shared goals. These mechanisms translate abstract exercise benefits into tangible, immediate rewards.

Meta-analytic evidence suggests gamification can enhance engagement, though effects vary by design quality [18,19]. However, two critical gaps exist in current evidence. First, vocational education remains understudied in gamification research, which has primarily focused on general university or K-12 settings [20]. Second, methodologically, most studies employ standard pretest-posttest designs that cannot account for measurement reactivity, where baseline assessment may influence subsequent responses [21-23].

To address these gaps, the primary objective of this study was to determine whether a gamified physical education intervention improves learning motivation, physical fitness, and mental health outcomes among Chinese vocational college students, while controlling for potential measurement artifacts through a Solomon four-group design.

Three specific research aims were established: (1) to evaluate the effects of gamified PE on physical fitness (PF), mental health (MH), and learning motivation (LM) in vocational education settings; (2) to validate these intervention effects by statistically ruling out pretest sensitization using the Solomon four-group

methodology; and (3) to examine whether satisfaction of basic psychological needs (competence, autonomy, relatedness) mediates the relationship between gamification and motivational outcomes.

Based on Self-Determination Theory and prior gamification research, three hypotheses were formulated: (H1) gamified PE would significantly improve PF, MH, and LM outcomes compared to traditional PE, regardless of pretest administration; (H2) intervention effects on motivation would be mediated by psychological need satisfaction; and (H3) treatment effects would remain consistent across both pretested and non-pretested conditions, indicating absence of measurement reactivity.

MATERIAL AND METHODS

Research Design

This study employed a Solomon four-group experimental design [24]. Participants were randomly assigned to one of four conditions using a computer-generated sequence: Experimental Group 1 (EG1): Pretest + Gamification + Posttest; Experimental Group 2 (EG2): No Pretest + Gamification + Posttest; Control Group 1 (CG1): Pretest + Traditional PE + Posttest; Control Group 2 (CG2): No Pretest + Traditional PE + Posttest. This design allows isolation of the main intervention effect, pretest sensitization effect, and their interaction [22,25].

Sample Size Determination

A priori power analysis was conducted using G*Power 3.1 [26]. Based on previous gamification studies in PE reporting medium-to-large effects (d = 0.50-0.80) [18,19], we assumed a medium effect size (f = 0.25) for the primary 2 × 2 factorial ANOVA. With α = 0.05 and power = 0.80, the minimum required sample size was 180 participants. To account for potential attrition (estimated at 10%), we recruited 200 participants (50 per group), providing adequate power for detecting main effects and interactions.

Participants and Setting

Participants were recruited from Nanchang Health Vocational and Technical College. This setting was selected because health-profession students face high academic stress yet require physical literacy for their careers [6]. Inclusion criteria ensured a homogeneous sample of first-year students (N = 200), balanced for gender and major. Data collection was conducted from February 2024 to June 2024.

Ethics Statement

This study was conducted according to the Declaration of Helsinki guidelines and approved by the Ethics Committee of Nanchang Health Vocational and Technical College (Approval No.: NCHVC-2023RT-2506). All participants provided written informed consent prior to participation.

Intervention

The intervention was designed based on SDT principles:
- Competence Support: Students earned points for skill mastery and effort rather than normative performance. A custom mobile application provided immediate digital feedback [27].
- Relatedness Support: Participants formed fixed teams (4-5 members), shifting focus from individual performance to collective success [28].

- Autonomy Support: Students selected activity paths and challenge levels (e.g., Novice vs. Pro difficulty).
- Mobile Application Limitations: The proprietary mobile application used for feedback and point tracking was developed specifically for this study. While this ensured alignment with SDT principles, it introduces potential technological bias. The application required smartphone ownership and basic digital literacy. Additionally, the novelty of the digital interface may have contributed to engagement beyond the gamification mechanisms themselves.
- Each 90-minute gamified class followed a structured cycle: Task Briefing (10 min), Skill Acquisition (30 min), Team Activities (40 min), and Summary/Rewards (10 min). Control groups received identical physical content via standard direct instruction without digital elements or team competition structures. The intervention spanned 16 weeks.

Outcome Measures
- PF: Assessed via the National Student Physical Health Standards including BMI, cardiovascular endurance, and strength components [29].
- MH: Measured using the Depression Anxiety Stress Scale-21 (DASS-21) [30], validated in Chinese college populations (Cronbach's α > 0.80) [28].
- Learning Motivation (LM): Evaluated using the Physical Activity and Leisure Motivation Scale (PALMS) [31].
- Mediators: Basic Psychological Needs in Exercise Scale (BPNES) [31].

Statistical Analysis

Assumption Testing: Prior to parametric analyses, data were examined for normality using Shapiro-Wilk tests [32] and Q-Q plots. Homogeneity of variance was assessed using Levene's test [33]. All primary outcome variables met normality assumptions (Shapiro-Wilk p > 0.05) and demonstrated homogeneous variances across groups (Levene's test p > 0.05), supporting the use of parametric methods.

Missing Data Handling: Three participants had incomplete post-test data (EG1: n = 2 due to injury/illness; CG1: n = 1 due to academic leave; overall attrition rate = 1.5%). Little's MCAR test indicated data were missing completely at random (χ^2 = 8.42, df = 12, p = 0.752) [34]. Multiple imputation (MI) was performed using fully conditional specification with 20 imputations, following established guidelines for handling missing data in intervention research [35]. All analyses were conducted on the imputed datasets, with results pooled according to Rubin's rules [36].

Primary Analyses: A 2 (Intervention: Gamification vs. Traditional) × 2 (Pretest: Yes vs. No) factorial ANOVA was conducted to detect testing artifacts. Upon confirming absence of sensitization, main effects were analyzed using independent t-tests on pooled groups.

Multiple Comparison Correction: For the component analysis of PF indicators (7 comparisons), Bonferroni correction was applied, adjusting the significance threshold to α = 0.05/7 = 0.007. Results are reported with both uncorrected and corrected significance levels. Similarly, for the Mental Health sub-scale analysis (3 comparisons: Stress, Anxiety, Depression), a Bonferroni correction was applied, setting the significance threshold at α = 0.05/3 ≈ 0.017.

Effect Sizes and Mediation: Cohen's d was calculated for between-group comparisons, interpreted as small (0.2), medium (0.5), or large (0.8) [37]. Mediation analysis was conducted using PROCESS Model 4 with 5,000 bootstrap samples [38]. All analyses were performed using SPSS 26.0.

RESULTS

Baseline Characteristics

Table 1 presents baseline demographic characteristics across all four groups. Chi-square tests and one-way ANOVA confirmed no significant differences in age (F = 0.94, p = 0.425), gender distribution (χ^2 = 0.18, p = 0.982), or baseline measures (all p > 0.05), confirming successful randomization.

Phase 1: Solomon Design Validation

Before assessing efficacy, internal validity was verified (see Figure 1 for participant flow). All 200 randomized participants were included in intention-to-treat analyses; three participants with incomplete post-test data (EG1: n = 2, injury/illness; CG1: n = 1, academic leave) were handled via multiple imputation as described in Methods. As shown in Table 2, the 2 × 2 ANOVA revealed no significant main effects for pretest condition across PF (p = 0.436), MH (p = 0.552), or LM (p = 0.154). No significant Pretest × Intervention interactions were found (all p > 0.05). This confirms that observed improvements were driven by the intervention, not measurement reactivity.

Phase 2: Main Intervention Effects

Following the validation of the Solomon design, independent t-tests were conducted on the pooled data. As presented in Table 3 and illustrated in Figure 2, the experimental group demonstrated superior outcomes compared to the control group across all primary domains. Specifically, LM showed the most pronounced improvement (t = 6.90, p < 0.001, d = 0.98). Similarly, the aggregate PF score was significantly higher in the gamified group (t = 4.36, p < 0.001, d = 0.62). For MH, the experimental group reported significantly lower scores (indicating better health) compared to controls (t = -4.98, p < 0.001, d = 0.70).

Phase 3: Component Analysis of Physical Fitness

To determine the specificity of the training effects, a detailed component analysis was performed across the seven physical fitness indicators. As shown in Table 4 and visualizing the standardized differences in Figure 3, the intervention produced non-uniform adaptations. Robust improvements were observed in locomotor-based metrics: Cardiovascular Endurance (800/1000m Run: p = 0.002, d = 0.44) and Sprint Speed (50m Sprint: p = 0.002, d = 0.45) both reached statistical significance. However, in contrast to the aerobic gains, Muscular Strength (assessed via Pull-ups/Sit-ups) showed no statistically significant difference between groups (t = 1.36, p = 0.176). Similarly, Body Mass Index（BMI）scores remained stable across the intervention period for both groups, showing no significant intervention effect (p > 0.05 for change scores).

Table 1. Baseline Characteristics and Group Equivalence

Variable	EG1 (n=50)	EG2 (n=50)	CG1 (n=50)	CG2 (n=50)	Statistics	*p*
Age (Mean ± SD)	19.6 ± 0.7	19.7 ± 0.8	19.4 ± 0.7	19.5 ± 0.7	F = 0.94	0.425
Gender (Male %)	36.0%	36.0%	38.0%	34.0%	χ^2 = 0.18	0.982
Pre-test PF	67.66 ± 7.82	-	67.67 ± 8.82	-	t = -0.01	0.995
Pre-test MH	26.32 ± 10.27	-	28.84 ± 8.66	-	t = -1.33	0.188
Pre-test LM	129.78 ± 14.57	-	132.84 ± 13.39	-	t = -1.09	0.277

EG1=Experimental Group 1 (Pretest + Gamification); EG2=Experimental Group 2 (No Pretest + Gamification); CG1=Control Group 1 (Pretest + Traditional); CG2=Control Group 2 (No Pretest + Traditional); PF=Physical Fitness; MH=Mental Health; LM=Learning Motivation
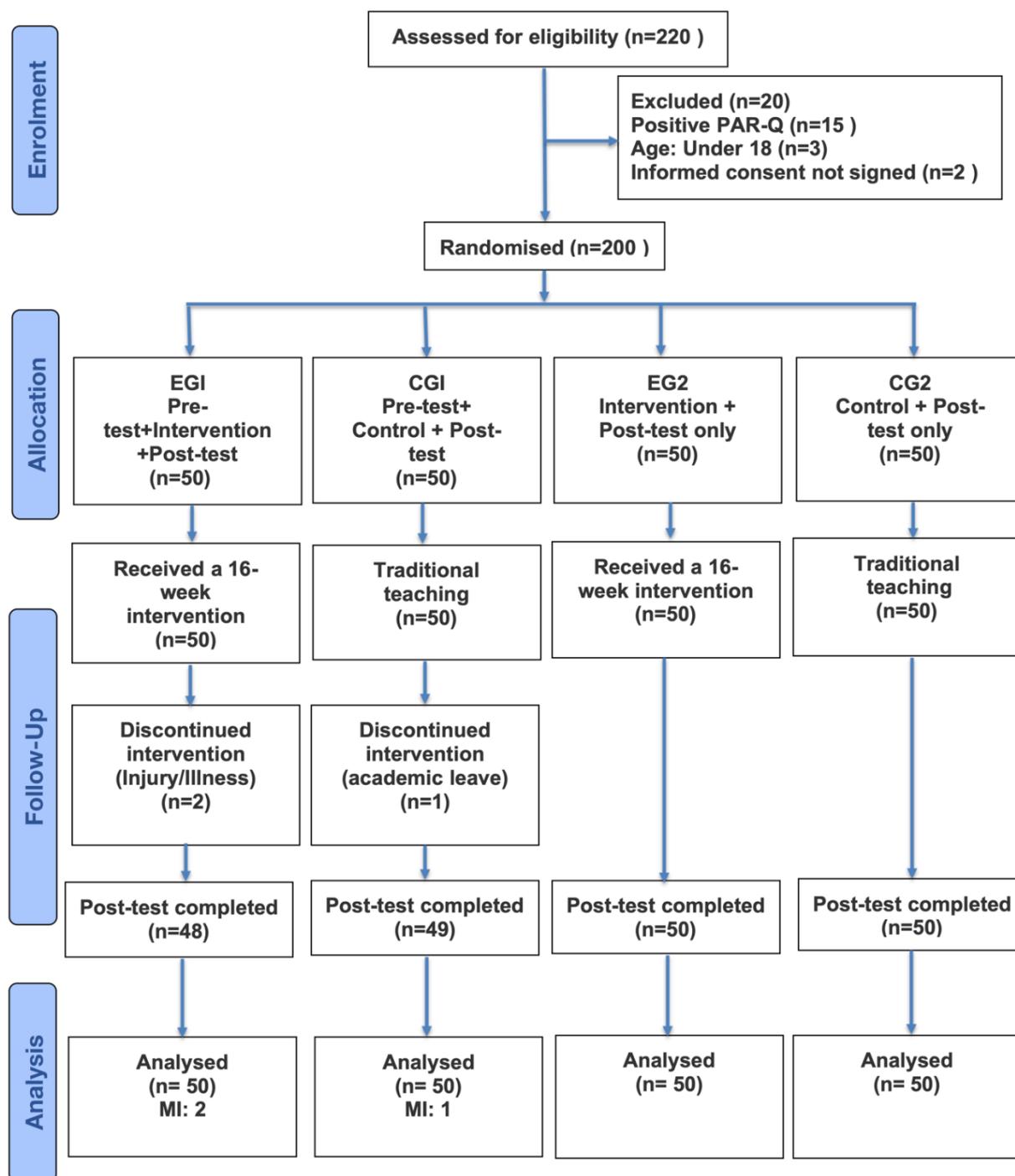
Figure 1. CONSORT Flow Diagram for Solomon Four-Group Design. Note: The diagram details participant enrollment, random allocation to four conditions, follow-up, and analysis.

Table 2. Analysis of Variance for Pretest Sensitization Effects

Outcome	Source	$F(1,196)$	p	ηp^2	Conclusion
PF	Pretest Main Effect	0.61	0.436	0.003	No Sensitization
	Group × Pretest	0.16	0.688	0.001	Valid to Pool
MH	Pretest Main Effect	0.36	0.552	0.002	No Sensitization
	Group × Pretest	1.05	0.307	0.005	Valid to Pool
LM	Pretest Main Effect	2.04	0.154	0.010	No Sensitization
	Group × Pretest	0.28	0.596	0.001	Valid to Pool

ηp^2 = partial eta squared. PF = Physical Fitness; MH = Mental Health (lower scores indicate better health); LM = Learning Motivation

Table 3. Comparison of Post-Intervention Outcomes

Outcome	Experimental	Control	t	p	Cohen's d
LM	149.16 ± 14.48	133.17 ± 18.09	6.90	<0.001	0.98
MH[a]	21.72 ± 9.09	28.22 ± 9.38	-4.98	<0.001	0.70
PF	74.13 ± 9.09	68.36 ± 9.63	4.35	<0.001	0.62

Values are Mean ± SD. LM = Learning Motivation; MH = Mental Health; PF = Physical Fitness. [a]For MH (DASS-21), lower scores indicate better psychological health

Table 4. Component Analysis of Physical Fitness Indicators

Indicator	Experimental	Control	t	p	Cohen's d
800/1000m Run	14.47 ± 3.97	12.45 ± 5.25	3.08	0.002**	0.44
Vital Capacity	10.68 ± 3.04	9.64 ± 3.72	2.17	0.031*	0.31
50m Sprint	14.83 ± 4.14	12.77 ± 4.92	3.20	0.002**	0.45
Standing Long Jump	7.26 ± 2.03	6.62 ± 2.37	2.06	0.041*	0.29
Pull-ups/Sit-ups	6.70 ± 2.31	6.25 ± 2.44	1.36	0.176	0.19
Sit and Reach	7.34 ± 1.73	6.72 ± 2.14	2.27	0.024*	0.32
BMI Score	12.84 ± 2.26	13.92 ± 1.57	-3.93	<0.001**	-0.56

Values are national standard scores. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The Pull-ups/Sit-ups metric (Muscular Strength) did not reach statistical significance
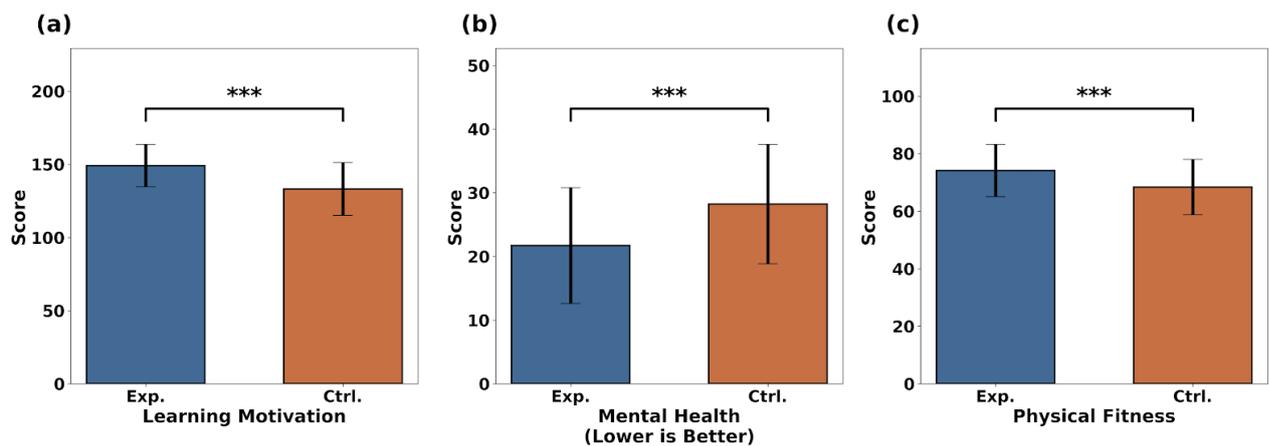

Figure 2. Comparison of Post-Intervention Outcomes (Pooled Data). Note: Bars represent mean scores with standard deviation error bars. Significance levels: *** $p < 0.001$. MH scores are inverted for visualization (higher bars = better MH); Exp. = Experimental; Ctrl. = Control
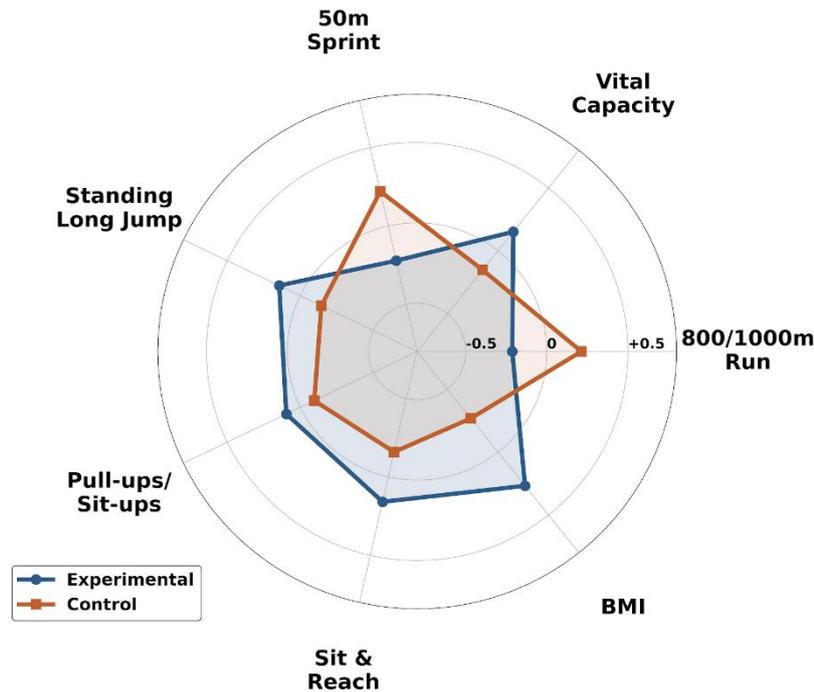
Figure 3. Comparative PF Profile (Z-Scores). The experimental group shows expansion in aerobic and speed domains, while strength (Pull-ups/Sit-ups) remains comparable to controls.
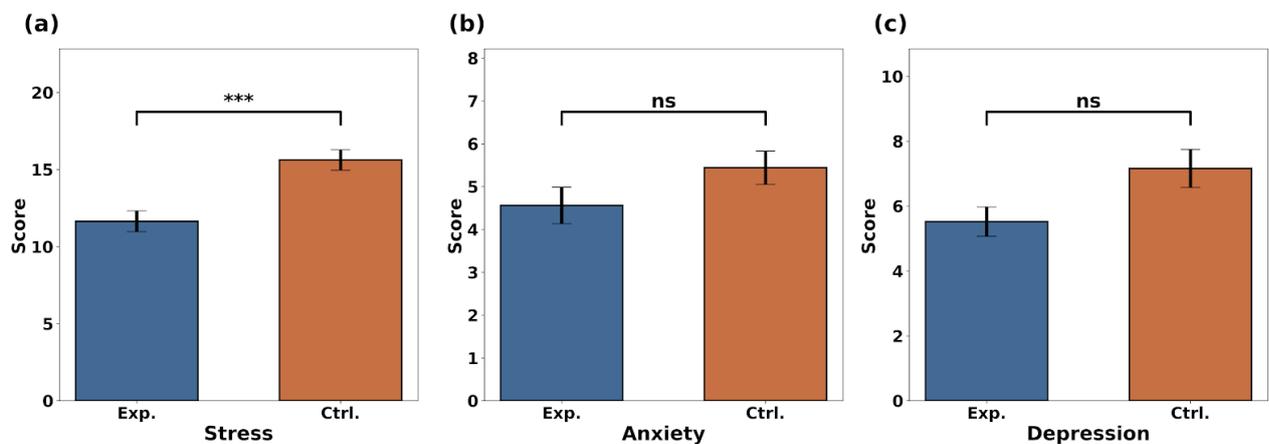

Figure 4. MH Sub-scale Analysis. Note: *(a) Stress scores were significantly lower in the gamified group (*** p < 0.001). (b) Anxiety and (c) Depression scores showed no statistically significant differences (ns); Exp. = Experimental; Ctrl. = Control

Phase 4: Mental Health Sub-scale Analysis

　　　　Further analysis of the DASS-21 sub-scales (Figure 4) clarified the specific nature of the mental health benefits. The intervention effect was predominantly driven by a significant reduction in Stress scores ($p < 0.001$). In contrast, no significant between-group differences were observed for Anxiety ($p = 0.129$) or Depression ($p = 0.028$, not significant after Bonferroni correction), suggesting the gamified

intervention was effective for managing proximal stress but less impactful on distal psychological symptoms.

Phase 5: Mediation Analysis

Mediation modeling (PROCESS Model 4) revealed that Competence Satisfaction was the dominant mediator ($\beta = 0.853$, $p < 0.001$), explaining approximately 43% of the total variance in motivation outcomes. In comparison, the indirect effects of Autonomy ($\beta = 0.12$) and Relatedness ($\beta = 0.31$) were significantly weaker.

DISCUSSION

The primary objective of this study was to evaluate the efficacy of gamified PE in a vocational setting while methodologically controlling for testing artifacts. Three critical findings emerged: (1) gamification generated a large effect on learning motivation ($d = 0.98$) without the confounding influence of pretest sensitization; (2) physical fitness improvements were domain-specific, benefiting locomotor skills but not muscular strength; and (3) competence satisfaction emerged as the singular dominant mechanism explaining motivational gains, a pattern distinct from Western SDT literature.

Interpretation of Motivational Outcomes

The observed effect on learning motivation ($d = 0.98$) is notably robust. This effect size substantially exceeds the meta-analytic average of $d = 0.67$ reported by Sailer and Homner [39] and is more than double the effect reported in Hanus and Fox's longitudinal classroom study ($d = 0.41$) [40]. The magnitude of this gain may be attributed to the "baseline deficit" effect; our sample of vocational students reported low initial self-efficacy, a demographic characteristic that often yields larger response rates to competence-supportive interventions compared to high-achieving university populations [41].

Nuances in Physical Fitness Adaptations

Regarding physical fitness, the results reveal a clear divergence based on training specificity. We observed significant improvements in 800/1000m run performance ($d = 0.44$) and sprint speed ($d = 0.45$). This aligns closely with Ferriz-Valero et al. [42], who reported similar gains in aerobic capacity ($d = 0.58$) in gamified university PE. These results are logical given that our gamified mechanics (e.g., tag games, relay pursuits) inherently emphasized continuous locomotion.

However, in contrast to our initial hypothesis, no significant improvements were found in muscular strength (pull-ups/sit-ups, $p = 0.176$) or BMI ($p > 0.05$). This null result for BMI is consistent with the meta-analysis by Gao et al. [43], which found active video games typically yield negligible effects on body composition ($d = 0.21$) without concurrent dietary restriction. The lack of strength gains likely reflects a design limitation: the intervention prioritized "flow" and continuous play over the static, high-resistance repetitions required for hypertrophy. While effective for cardio-metabolic health, gamification design must evolve to include dedicated "strength power-up" modules if comprehensive fitness is the goal.

Mental Health: Proximal vs. Distal Effects

The mental health findings present a specific dichotomy: while stress was significantly reduced ($d = 0.59$), anxiety and depression remained unchanged. This

result diverges from Biddle and Asare's review [44], which generally associates physical activity with reductions in depression (d = 0.41). We interpret this discrepancy through the lens of *proximal* versus *distal* stressors. The "stress" measured here largely reflects immediate academic and daily pressure, which is responsive to the acute enjoyment of gamified play. Conversely, the anxiety and depression reported by Chinese vocational students are often rooted in structural challenges—such as uncertainty regarding future employment and societal stigma attached to vocational education. These are systemic, distal stressors that a 16-week PE intervention is unlikely to resolve.

Mediation Analysis: The Cultural Primacy of Competence

Perhaps the most theoretically significant finding is the overwhelming dominance of competence satisfaction (β = 0.853) in mediating motivation, while autonomy (β = 0.12) played a negligible role. This pattern stands in sharp contrast to Western SDT research (e.g., Reeve & Jang [45]), where autonomy support is typically the strongest predictor of engagement.

Two analytical frameworks explain this divergence. First, from a cultural perspective, this finding resonates with cross-cultural SDT studies suggesting that in collectivist, exam-oriented educational systems, "success" is often defined by mastery and external validation rather than independent choice [46,47]. For vocational students who have historically experienced academic setbacks, the explicit, quantified feedback provided by points and leaderboards (Competence) may fulfill a more urgent psychological deficit than the provision of choice (Autonomy). Second, from an intervention design perspective, this imbalance may reflect the specific mechanics of the gamification used. The system provided high-frequency competence feedback (scores updated instantly), whereas autonomy was limited to constrained choices. Future research should distinguish whether this competence dominance is a fixed cultural trait of Chinese vocational students or a byproduct of rigid gamification design.

Limitations and Future Directions

Several limitations constrain the interpretation of these findings and suggest avenues for future research.

First, regarding intervention design and physiological specificity, the gamified protocol prioritized continuous locomotor engagement (e.g., tag games, relay pursuits) to maintain game narrative and "flow." While this successfully improved cardiovascular endurance, it resulted in insufficient resistance training stimuli, explaining the observed lack of improvement in muscular strength. Future gamified PE interventions should adopt a "hybrid" design that explicitly gamifies static resistance exercises (e.g., "boss battles" requiring specific repetitions of pull-ups or squats) to ensure comprehensive physical development.

Second, the reliance on self-report measures for mental health and motivation introduces potential common method bias. Although our results for stress reduction were robust, future studies should incorporate objective physiological markers (e.g., cortisol levels, heart rate variability) and behavioral metrics (e.g., voluntary class attendance, extra-curricular physical activity logs) to triangulate these psychological findings.

Third, the single-institution design limits generalizability. As vocational students in different regions may face varying academic pressures and cultural expectations, multi-site replication studies are essential to determine whether the dominant role of competence satisfaction observed here is a universal characteristic of Chinese vocational populations or specific to this sample.

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Finally, while the mediation analysis identified competence as the primary driver, the cross-sectional measurement of mediators precludes strict causal inference. Future research should employ longitudinal mediation models with multiple assessment points to establish the temporal precedence of need satisfaction in the gamification-motivation relationship.

CONCLUSION

This study provides methodologically rigorous evidence that structured gamification based on Self-Determination Theory is a highly effective pedagogical strategy for the vocational education context. The Solomon four-group design confirmed that the observed benefits were genuine intervention effects, free from pretest sensitization artifacts.

Specifically, the intervention generated substantial gains in learning motivation ($d = 0.98$) and cardiorespiratory fitness (endurance and speed). However, the absence of significant improvements in muscular strength suggests that gamification strategies must be carefully tailored to target specific fitness components; mere "gameplay" is insufficient for holistic physical conditioning without targeted resistance mechanics. Furthermore, the findings highlight a unique motivational mechanism in this population: competence satisfaction emerged as the singular dominant driver of engagement. For educators, this suggests that PE curricula for vocational students should prioritize systems that provide immediate, tangible feedback on skill mastery over those that simply offer unstructured choice.

Conflicts of Interest: The authors declare no conflict of interest.

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