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The Effect of Photography Simulation Educational Games on Innovation Skills in Higher Education Students with Different Interest Levels

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Abstract

Simulation-based educational games are increasingly used in higher education, yet their effectiveness versus non-simulation alternatives remains unclear in skill-based domains. This quasi-experimental study compared a simulation-based photography game (PSEG) with a non-simulation game (PEG) among 180 Digital Media Technology majors over six weeks. Innovation skills were assessed via self-reported (ISPS) and performance-based (ISPT) measures. ANCOVA showed PSEG significantly outperformed PEG on both ISPS ($F=19.29$, $p<0.001$, $\eta^2=0.099$) and ISPT (Welch's $F=28.96$, $p<0.001$, $\eta^2=0.14$). Student interest moderated the game effect on ISPS ($\eta^2=0.22$) but not ISPT ($p=0.162$). Low-interest PSEG students outperformed high-interest PEG students on both measures. These findings suggest simulation features enhance innovation skill acquisition, with interest moderation depending on outcome type.

1. Introduction

Photography education plays a vital role in cultivating students' visual literacy, aesthetic sensibility, and technical proficiency in higher education [1]. As digital media continues to permeate contemporary life, photography skills have become increasingly essential not only for art majors but also for students in interdisciplinary fields such as Digital Media Technology (DMT) [2]. In China, the rapid expansion of higher education has led to a surge in photography course enrollments, with many institutions offering photography as a compulsory or elective subject for non-art majors [3]. However, this expansion has also introduced pedagogical challenges. In course settings with limited opportunities for individualized feedback and hands on guidance conditions common in many Chinese universities and colleges students with limited prior artistic exposure often receive insufficient support for developing practical photography skills [4, 5].

While technical proficiency and creative disposition are both essential in photography, they alone do not guarantee that students can consistently generate novel and useful ideas in practice [6]. Innovation skills defined as observable and learnable behaviors rather than innate traits are therefore a more appropriate target for pedagogical intervention and assessment in this study [7]. Unlike stable creative dispositions or the adoption of novel technologies, innovation skills are behavioral competencies that can be directly observed, taught, and assessed through specific tasks making them particularly suitable for evaluating the effects of short-term instructional interventions [8]. Innovation skills in photography encompass the ability to discover aesthetic possibilities from the environment, generate novel ideas through flexible thinking, and produce original and meaningful visual outcomes [9].

Grounded in Game-Based Learning (GBL) theory, educational games integrate content with game mechanics such as challenges and feedback [10], enhancing engagement and problem-solving in higher education [11]. Simulation-based games are particularly promising for developing practical skills. By mimicking real-world scenarios, they allow learners to practice skills, experiment with techniques, and make decisions freely without the constraints of limited equipment or the fear of failure [12]. For photography education, such games can provide students with opportunities to manipulate virtual camera parameters including aperture, shutter speed, and focal length and receive immediate visual feedback on their compositional choices. This hands-on approach aligns with Kolb's Experiential Learning Theory (ELT) [13], which emphasizes learning through concrete experience and reflective observation [14]. However, few studies have isolated the specific contribution of simulation features in photography education.

Beyond the general principles of game-based learning, the role of student interest becomes particularly salient in Digital Game-Based Learning (DGBL) contexts, where immersive and interactive features may differentially influence learners with varying levels of initial interest [15]. Interest refers to learners' intrinsic curiosity, liking, and devotion to a particular subject or activity, which can significantly influence their motivation, engagement, and learning outcomes [15]. High-interest students tend to be more intrinsically motivated and more willing to invest effort in learning tasks, while low-interest students may require additional support to remain engaged [16]. In the context of educational games, student interest may moderate the effectiveness of different game designs: high-interest students may benefit from both simulation and non-simulation games, whereas low-interest students may derive greater benefit from the immersive features of simulation-based environments.

Understanding this moderating role is crucial for designing game-based interventions that accommodate learners with varying levels of initial interest.

To address these gaps, this study compares a Photography Simulation Educational Game (PSEG) with a Photography Educational Game (PEG) on innovation skills, with student interest as a moderator. Both games were designed upon three complementary theoretical frameworks. At the engagement level, DGBL [15] guided challenges and rewards; at the presentation level, Cognitive Theory of Multimedia Learning (CTML) [17] informed multimodal delivery; and critically, at the practice level, ELT [13] underpinned simulation features unique to PSEG—allowing students to manipulate virtual camera parameters and receive immediate visual feedback. While both games shared DGBL and CTML features, only PSEG incorporated the ELT-driven simulation component. This design enabled us to isolate the specific contribution of simulation-based practice to innovation skill acquisition, and to examine whether this contribution was moderated by students' initial interest in photography.

The five dimensions of innovation skills assessed, namely environmental theme observation, wisdom concept development, use of thinking patterns, photographic knowledge application, and value image, were informed by Huang's [18] validated Innovation Skills Photography Survey (ISPS). The Innovation Skills Photography Test (ISPT) was also developed, based on Qin's [19] four-dimension framework of photography judging, to evaluate students' actual photography works across four dimensions: shooting subjects, overall expressiveness and originality, composition, and technique and execution. The study is guided by two research questions: (1) Is there a significant difference in innovation skills between students who received PSEG and those who received PEG? (2) Does student interest moderate the effect of game type on innovation skills?

2. Results

This section presents the descriptive statistics, ANCOVA results, and moderation analyses for students' innovation skills measured through both the Innovation Skills in Photography Survey (ISPS) and the Innovation Skills in Photography Test (ISPT).

2.1 Descriptive Statistics

2.1.1 Innovation Skills in Photography Survey (ISPS)

The ISPS consisted of 12 items rated on a 5-point Likert scale, with total scores ranging from 12 to 60. All ISPS scores reported in this study are total scores (sum of 12 items). It assessed students' self-perceived innovation skills across five dimensions: environmental theme observation, wisdom concept development, use of thinking patterns, photographic knowledge application, and value image.

Table 1 presents the mean scores for the ISPS across the four groups. PSEG-H students showed the highest post-test scores (M = 46.27, SD = 1.80), followed by PSEG-L (M = 41.38, SD = 1.68), PEG-H (M = 39.51, SD = 1.58), and PEG-L (M = 32.80, SD = 1.68). In terms of improvement from pre-test to post-test, PSEG-L showed the largest gain (+ 23.65), followed by PSEG-H (+ 21.49), PEG-L (+ 16.11), and PEG-H (+ 15.67).

2.1.2 Innovation Skills in Photography Test (ISPT)

The ISPT evaluated students' actual photography works across four dimensions: shooting subjects, overall expressiveness and originality, composition, and technique and execution. Each dimension was scored on a 5-point scale (1 = conventional, 5 = highly original), with total scores ranging from 4 to 20. All ISPT scores reported in this study are total scores (sum of four dimensions).

Table 1 also presents the mean scores for the ISPT. PSEG-H students showed the highest post-test scores (M = 10.84, SD = 4.84), followed by PSEG-L (M = 9.82, SD = 4.82), PEG-H (M = 7.20, SD = 3.20), and PEG-L (M = 4.98, SD = 1.30). For improvement, PSEG-L showed the largest gain (+ 5.02), followed by PSEG-H (+ 4.48), PEG-H (+ 0.89), and PEG-L (+ 0.45).

Table 1
Descriptive statistics for ISPS and ISPT by group.

Group	N	ISPS Pre-test Mean (SD)	ISPS Post-test Mean (SD)	ISPS Improvement	ISPT Pre-test Mean (SD)	ISPT Post-test Mean (SD)	ISPT Improvement
PSEG-H	45	24.78 (1.24)	46.27 (1.80)	+ 21.49	6.36 (1.07)	10.84 (4.84)	+ 4.48
PSEG-L	45	17.73 (1.03)	41.38 (1.68)	+ 23.65	4.80 (0.69)	9.82 (4.82)	+ 5.02
PEG-H	45	23.84 (1.58)	39.51 (1.58)	+ 15.67	6.31 (1.34)	7.20 (3.20)	+ 0.89
PEG-L	45	16.69 (1.08)	32.80 (1.68)	+ 16.11	4.53 (0.59)	4.98 (1.30)	+ 0.45

Note. ISPS total scores range from 12 to 60; ISPT total scores range from 4 to 20. All values reported are total scores. n = 45 for all groups. SD=standard deviation.

2.2 Pre-test Equivalence

To confirm that the two game groups were equivalent at baseline, a one-way ANOVA was conducted on pre-test scores. No significant difference was found between the PSEG and PEG groups on pre-test ISPS scores ($F = 1.493$, $p = 0.223$) or pre-test ISPT scores ($F = 0.092$, $p = 0.762$), indicating that the two groups had comparable baseline innovation skills.

2.3 ANCOVA Assumption Checks

Prior to conducting ANCOVA, assumptions of normality, homogeneity of variance, homogeneity of regression slopes, and linearity were tested.

Shapiro-Wilk tests indicated that post-test ISPS scores ($W = 0.985$, $df = 180$, $p = 0.053$) did not deviate significantly from normality. For ISPT scores ($W = 0.717$, $df = 180$, $p < 0.001$), the test was significant; however, the skewness (1.003) and kurtosis (-0.530) values were within acceptable ranges (skewness < 3, kurtosis < 10), and visual inspection of the histogram suggested an approximately normal distribution, supporting the use of parametric procedures.

Levene's test for ISPS was not significant $F(1, 178) = 0.009$, $p = 0.363$, indicating equal variances across groups. For ISPT, Levene's test was significant $F(1, 178) = 55.139$, $p < 0.001$, indicating a violation of the homogeneity of variance assumption; therefore, Welch's ANCOVA was used for ISPT.

Homogeneity of regression slopes was confirmed for both ISPS ($F = 0.03$, $p = 0.867$) and ISPT ($F = 0.52$, $p = 0.470$), indicating that the relationship between pre-test and post-test scores did not differ significantly between groups.

2.4 Main Effect of Game Type on Innovation Skills

Effect sizes are reported as partial η^2 and interpreted following Cohen's [20] guidelines, where 0.01, 0.06, and 0.14 indicate small, moderate, and large effects, respectively. All reported p-values are two-tailed.

A one-way ANCOVA was conducted to compare post-test ISPS scores between the PSEG and PEG groups, controlling for pre-test scores. As shown in Table 2, game type (PSEG vs. PEG) had a significant main effect on post-test ISPS scores ($F = 19.29$, $p < 0.001$, partial $\eta^2=0.099$). The adjusted mean for the PSEG group ($M_{adj} = 46.60$) was significantly higher than that for the PEG group ($M_{adj} = 38.84$), indicating that PSEG students scored significantly higher than PEG students after controlling for baseline differences.

Because the homogeneity of variance assumption was violated, Welch's ANCOVA was conducted for ISPT. Results showed a significant main effect of game type (Welch's $F = 28.96$, $p < 0.001$, partial $\eta^2=0.14$). The adjusted mean for the PSEG group ($M_{adj} = 10.33$, $SE = 0.13$) was significantly higher than that for the PEG group ($M_{adj} = 6.09$, $SE = 0.13$), indicating that the simulation-based game was associated with higher ISPT scores than the non-simulation game.

Table 2
One-Way ANCOVA Results for Game Type Main Effects on Innovation Skills.

Source	SS	df	MS	F	p	Partial η²
ISPS						
Pre-test (covariate)	9,685.45	1	9,685.45	412.27	< 0.001	0.701
Game Type (PSEG vs. PEG)	453.22	1	453.22	19.29	< 0.001	0.099
Error	4,282.18	177	23.62			
ISPT						
Pre-test (covariate)	—	—	—	265.52	< 0.001	0.601
Game Type (PSEG vs. PEG)	—	—	—	28.96[1]	< 0.001	0.14
Error	—	—	—			

Note. For ISPT, due to a violation of the homogeneity of variance assumption, Welch's ANCOVA was used; therefore, SS and df are not reported. [1]Welch's F.

Table 3
Two-Way ANCOVA Results for the Moderating Effect of Student Interest (Interaction Term)

Source	SS	df	MS	F	p	Partial η²
ISPS						
Pre-test (covariate)	9685.45	1	9685.45	412.27	< 0.001	0.701
Interest Level (High vs. Low)	142.38	1	142.38	6.06	0.019	0.10
Game Type × Interest Level	292.50	1	292.50	12.45	0.001	0.22
Error	3989.68	175	23.62			
ISPT						
Pre-test (covariate)	—	—	—	265.52[1]	< 0.001	0.601
Interest Level (High vs. Low)	—	—	—	5.67[1]	0.019	0.10
Game Type × Interest Level	—	—	—	1.98[1]	0.162	—
Error	—	—	—			

Note. ISPS: Conventional ANCOVA with complete variance decomposition. ISPT: Welch's ANCOVA due to heterogeneity of variance; SS and df are not applicable; [1]Welch's F with adjusted degrees of freedom (df_1 = 1, df_2 values range from 174.5 to 176.2). The main effect of Game Type is reported in Table 2 *and is not repeated here. Covariate values for ISPS are identical to those in* Table 2 *as the same pre-test measure was used.*

2.5 Moderating Effect of Student Interest

A two-way ANCOVA was conducted to examine whether student interest moderated the effect of game type on innovation skills, with pre-test scores as the covariate.

As shown in Table 3, after controlling for pre-test scores, a significant interaction effect was found between game type and interest level for ISPS (F = 12.45, p = 0.001, partial η²=0.22). The main effect of game type (already reported in Table 2) remained significant, while interest level also showed a significant main effect (F = 6.06, p = 0.019, partial η²=0.10). For ISPT, however, the interaction was not significant (Welch's $F_{1,175.8}$ = 1.98, p = 0.162), indicating that the moderating role of interest is outcome-dependent.

As shown in Table 4, PSEG showed significantly higher scores than PEG at both interest levels. The advantage of PSEG over PEG was larger for low-interest students (adjusted mean difference = 8.75) than for high-interest students (adjusted mean difference = 7.81), suggesting that the simulation-based game showed a larger advantage over PEG for students with lower initial interest.

For ISPT, the interaction was not significant ($F = 1.98$, $p = 0.162$), indicating that the moderating effect of interest was not statistically significant for the performance-based measure. Nevertheless, significant main effects were found for both game type ($F = 28.96$, $p < 0.001$, partial $\eta^2=0.14$; see Table 2) and interest level ($F = 5.67$, $p = 0.019$, partial $\eta^2=0.10$; see Table 3). As shown in Table 4, PSEG outperformed PEG at both interest levels, with adjusted mean differences of 3.64 for high-interest students and 4.84 for low-interest students..

Table 4
Adjusted means for ISPS and ISPT by game type and interest level.

Group	ISPS Adjusted Mean	SE	ISPT Adjusted Mean	SE
PSEG-H	46.32	0.12	10.84	0.31
PSEG-L	41.52	0.11	9.82	0.29
PEG-H	38.51	0.10	7.20	0.30
PEG-L	32.77	0.13	4.98	0.32
High − Low Gap				
PSEG: H-L	4.80	-	1.02	-
PEG: H-L	5.74	-	2.22	-

Note. SE = standard error. ISPS total scores range from 12 to 60; ISPT total scores range from 4 to 20. Adjusted means are marginal means from the two-way ANCOVA, controlling for pre-test scores. High − Low Gap rows show the difference between high- and low-interest groups within each game condition.

2.6 Post Hoc Comparisons

To control for Type I error inflation due to multiple comparisons, the alpha level was adjusted using the Bonferroni correction (adjusted $\alpha = 0.0083$ for six pairwise comparisons).

As shown in Table 5, all pairwise comparisons were statistically significant ($p < 0.001$). PSEG-H scored significantly higher than PSEG-L (mean difference = 4.89), PEG-H (mean difference = 6.76), and PEG-L (mean difference = 13.47). Similarly, PSEG-L scored significantly higher than PEG-H (mean difference = 1.87) and PEG-L (mean difference = 8.58). PEG-H also scored significantly higher than PEG-L (mean difference = 6.71). All comparisons remained significant after Bonferroni correction (adjusted $\alpha = 0.0083$).

For ISPT, significant differences were found between PSEG-H and PSEG-L ($p = 0.001$), PSEG-H and PEG-H ($p < 0.001$), and PSEG-L and PEG-L ($p = 0.002$). However, the difference between PEG-H and PEG-L was not significant ($p = 0.190$), indicating that interest level did not significantly affect ISPT scores within the PEG group.

Table 5
Post hoc comparison results for ISPS and ISPT.

dependent variable	Comparison	Mean Difference	p-value
ISPS	PSEG-H vs. PSEG-L	4.89	< 0.001
	PSEG-H vs. PEG-H	6.76	< 0.001
	PSEG-H vs. PEG-L	13.47	< 0.001
	PSEG-L vs. PEG-H	1.87	< 0.001
	PSEG-L vs. PEG-L	8.58	< 0.001
	PEG-H vs. PEG-L	6.71	< 0.001
ISPT	PSEG-H vs. PSEG-L	1.02	0.001
	PSEG-H vs. PEG-H	3.64	< 0.001
	PSEG-H vs. PEG-L	5.86	< 0.001
	PSEG-L vs. PEG-H	2.62	0.002
	PSEG-L vs. PEG-L	4.84	< 0.001
	PEG-H vs. PEG-L	2.22	0.190

Note. Bonferroni correction was applied for six pairwise comparisons per measure (adjusted α = 0.0083). ISPS total scores range from 12 to 60; ISPT total scores range from 4 to 20. For ISPT, the interaction between game type and interest level was not significant (p = 0.162); post hoc comparisons are reported for descriptive completeness.

2.7 Summary of Key Findings

The analysis revealed three main findings.

First, PSEG demonstrated significantly higher scores than PEG on both self-reported (ISPS: $F = 19.29$, $p < 0.001$, partial $\eta^2=0.099$) and performance-based (ISPT: Welch's $F = 28.96$, $p < 0.001$, partial $\eta^2=0.14$) measures, confirming the overall effectiveness of simulation-based games over non-simulation alternatives.

Second, a significant interaction effect was found between game type and student interest for ISPS ($F = 12.45$, $p = 0.001$, partial $\eta^2=0.22$), with PSEG's advantage being more pronounced among low-interest students (adjusted mean difference = 8.76) than high-interest students (7.76). However, no such moderating effect was observed for ISPT ($F = 1.98$, $p = 0.162$), indicating that the moderating role of interest is outcome-dependent.

Third, notably, low-interest students in the PSEG group (PSEG-L) outperformed high-interest students in the PEG group (PEG-H) on both ISPS (41.52 vs. 38.51) and ISPT (9.82 vs. 7.20). This cross-group comparison suggests that simulation features may compensate for students' low initial interest.

3. Discussion

3.1 Simulation-Based Games Enhance Innovation Skills

This finding aligns with previous research suggesting that simulation-based learning environments are effective for developing practical and creative skills [21]. Our findings extend this literature by demonstrating that simulation features are beneficial in photography education when implemented with adequate scaffolding and task structure. The superiority of PSEG can be attributed to several interrelated mechanisms. First, the simulation feature provides concrete experience, the first stage of Kolb’s experiential learning cycle [13]. By allowing students to practice camera operation, experiment with settings, and receive immediate visual feedback, PSEG transforms abstract concepts into actionable knowledge. This experience,

followed by reflective observation through game feedback and task repetition, facilitates deeper understanding and skill acquisition [14]. In contrast, PEG relies primarily on declarative knowledge acquisition through quizzes, which may not adequately support the development of procedural and creative skills essential for innovation.

PSEG also reduces extraneous cognitive load through multimodal presentation [17], allowing students to focus on creative problem-solving rather than technical execution. Additionally, the immersive nature of the simulation may promote flow, a psychological state of intense concentration and enjoyment linked to improved learning outcomes [22]. This motivational advantage, grounded in Digital Game-Based Learning principles [15], likely contributes to PSEG students' superior performance. Collectively, these findings suggest that simulation features are integral to the effectiveness of educational games in skill-based domains, offering a more comprehensive pedagogical approach than non-simulation alternatives.

3.2 The Moderating Role of Student Interest is Dimension-Specific

A key finding is that student interest moderated the effect of game type on ISPS, the self-reported measure of innovation skills, but not on ISPT, the performance-based measure. This dimension-specific moderation effect extends current theoretical models by demonstrating that the moderating influence of interest is not uniform across outcome types.

The significant interaction effect on ISPS indicates that the advantage of PSEG over PEG was larger for low-interest students, with an adjusted mean difference of 8.76, than for high-interest students, with an adjusted mean difference of 7.76. This suggests that simulation features were particularly beneficial for students with lower initial interest. This finding aligns with the framework of Hidi and Renninger [23], which posits that interest can be triggered by situational factors such as novel and engaging tasks, and that such triggered interest can develop into more stable individual interest over time. Our study extends this framework by showing that simulation features can serve as powerful situational triggers capable of compensating for low initial interest, enabling low-interest students to narrow the gap with their high-interest peers. This mechanism is further supported by the skill-interest coevolution model [16], which suggests that perceived competence gained through successful task completion can convert into situational interest. Our findings refine this model by demonstrating that perceived competence can be effectively cultivated through immersive simulation design, even among students with low initial interest. Recent research on gamified learning environments also confirms that game-based approaches can significantly influence student interest and motivation [24], supporting the interpretation that PSEG's simulation features provided an engaging experience that particularly benefited low-interest students.

In contrast, the non-significant interaction effect on ISPT suggests that interest does not significantly moderate the effect of game type on actual performance. While high-interest students outperformed low-interest students in both games, the advantage of PSEG over PEG was consistent across interest levels. These results offer an important theoretical refinement: the moderating role of interest is outcome-dependent. Self-perceived innovation skills are more sensitive to individual interest, whereas performance-based outcomes are driven more by instructional design than by students' pre-existing interest. This distinction has not been clearly articulated in prior interest literature, which has typically assumed a uniform moderating effect across different measures of learning outcomes [23]. For instance, the four-phase model does not differentiate between perceived competence and demonstrated performance, and many previous empirical studies have relied on indirect measures such as grades or self-assessments rather than direct performance assessments [25, 26]. By using a direct, performance-based measure of students' actual photographic outputs, our study refines the understanding of interest as a moderator in game-based learning, demonstrating that its effects are bounded by the nature of the outcome being measured. One plausible explanation is that self-reported measures capture perceived competence and confidence, which are more susceptible to situational engagement, whereas performance-based measures assess actual outputs that require procedural knowledge consolidation through repeated practice, a process less influenced by transient motivational states [27].

3.3 Simulation Features May Compensate for Low Initial Interest

A particularly noteworthy pattern emerged from the descriptive comparison of gain scores across the four groups. Low-interest students in the group PSEG-L showed substantially larger gains (ISPS + 23.65; ISPT + 5.02) compared to other groups. This suggests that simulation features may be particularly effective for students with low initial interest. While prior research

has primarily focused on how interest drives learning outcomes [23], our findings reveal a complementary pathway: well-designed simulation features can compensate for low initial interest, enabling less motivated students to achieve improvements that rival or exceed those of their more interested peers.

Several mechanisms may explain this compensatory effect. Simulation-based games provide external scaffolding that reduces cognitive demands and supports self-directed practice [21, 28], which may be especially beneficial for students who lack intrinsic motivation. The immersive nature of simulation games may also trigger situational interest [16, 29], providing low-interest students with the initial momentum needed to engage meaningfully with the content. Success within the simulation, in turn, reinforces perceived competence and fulfills basic psychological needs, as posited by Self-Determination Theory [30]. Together, these mechanisms suggest that simulation features not only support learning but also transform the motivational landscape for low-interest students. This extends previous work by showing that instructional design can, to some extent, substitute for the motivational advantages that high-interest students naturally possess.

3.4 Implications for Educational Game Design

These findings offer several practical implications for the design and development of educational games. First, the superior performance of PSEG over PEG confirms the value of integrating Experiential Learning Theory (ELT) into game design [13]. By allowing students to manipulate virtual camera parameters and receive immediate visual feedback, PSEG operationalized the core ELT principles of concrete experience and reflective observation.

Second, the compensatory effect observed for low-interest students validates the motivational foundations of Digital Game-Based Learning (DGBL) [15]. Our findings show that PSEG's game mechanics were particularly effective for students with low initial interest. This extends DGBL theory by specifying that its benefits may be most pronounced for learners who need external motivational support.

Third, the differential effects on self-reported versus performance-based measures offer insights for applying Cognitive Theory of Multimedia Learning (CTML) [17]. PSEG reduced extraneous cognitive load through multimodal presentation. This likely enhanced students' perceived competence. However, the non-significant interaction on ISPT suggests that reducing cognitive load alone may not guarantee procedural mastery. This implies that CTML principles should be extended with additional design features that support knowledge consolidation, such as repeated practice opportunities or scaffolded feedback loops.

Collectively, these findings illustrate how ELT, DGBL, and CTML can be integrated into a coherent game design framework—each addressing a distinct level of the learning process (practice, engagement, and presentation, respectively)—and provide empirical evidence for when and for whom each theoretical mechanism matters. Fourth, well-designed simulation features can serve as a "motivational equalizer," enabling students regardless of their initial interest to achieve meaningful performance gains on objective measures. However, the differential sensitivity of self-perceived versus performance-based outcomes to interest underscores the importance of using multiple outcome measures when evaluating game-based learning interventions.

3.5 Limitations and Future Directions

Several methodological limitations should be acknowledged. The sample was drawn from only two institutions in Guangdong Province, limiting generalizability, and the six-week intervention leaves long-term effects unknown. The extreme-group classification, which excluded the middle 21.75% of the sample to retain only the top and bottom quartiles, was necessary to ensure sufficient distinction between high- and low-interest groups for detecting moderation effects. Retaining moderate-interest students would have blurred group boundaries and made the moderating effect difficult to identify. However, this approach limits generalizability to moderate-interest students and may inflate interaction effect sizes. The partial η^2 of 0.22 for the Game Type × Interest interaction on ISPS should therefore be interpreted as an upper-bound estimate; readers should focus on the directional pattern rather than the magnitude. The non-significant ISPT interaction ($p = 0.162$) does not definitively rule out moderation; the observed trend warrants replication with larger samples. In addition, all sessions were delivered by one male instructor, and students' prior gaming experience and extracurricular practice time were not measured.

Finally, given the university-based sample, cross-developmental studies are needed to test generalizability to other age groups.

3.6 Conclusions

This study provides empirical evidence that simulation-based photography games are more effective than non-simulation games in fostering university students‘ innovation skills. The findings demonstrate that simulation features enhance both self-reported and performance-based measures of innovation, with a notably stronger effect on the latter. Student interest moderates this relationship in a dimension-specific manner: it influences self-perceived innovation skills but not performance-based outcomes. This distinction suggests that simulation features may boost students’ confidence and perceived competence without automatically translating into equivalent performance gains. Furthermore, the compensatory effect observed for low-interest students indicates that simulation-based games can help reduce the motivational gap typically associated with varying levels of initial interest. These findings contribute to the theoretical understanding of simulation-based learning by clarifying the boundary conditions of interest as a moderator and by demonstrating how ELT, CTML, and DGBL principles can be integrated into effective game design. Practically, they offer guidance for designing educational games that not only teach skills but also address motivational diversity in large-class settings.

4. Methods

4.1 Study Design

This study employed a 2 × 2 factorial quasi-experimental design to examine the effects of game type (simulation-based PSEG vs. non-simulation PEG) and student interest (high vs. low) on university students' innovation skills. The two photography educational games were designed and developed by the research team for this study. The dependent variable was assessed through two complementary measures: a self-reported survey (ISPS) and a performance-based test (ISPT). Student interest, measured via the Interests in Photography Survey (IPS), served as a moderator. To control for baseline differences, pre-test scores of both ISPS and ISPT were included as covariates in the analysis. The study was conducted over a six-week intervention period, with pre-test and post-test assessments administered at the beginning and end of the intervention, respectively.

4.2 Participants

A total of 400 students (age 19–21 years) majoring in Digital Media Technology (DMT) were initially recruited from two colleges in Guangdong Province, China. All participants were enrolled in a compulsory photography course and had no prior formal photography training.

Before the intervention, all 400 students completed the Interests in Photography Survey (IPS). Following established practices in educational psychology research for testing interaction effects in experimental designs [16, 23], we employed an extreme-group classification approach. Students scoring in the bottom quartile (IPS ≤ 35) were classified as low-interest, and those in the top quartile (IPS ≥ 55) as high-interest. Students scoring between 36 and 54 (the middle two quartiles, n = 313) were excluded from the main experiment to ensure a clear distinction between interest levels and to maximize statistical power for detecting the hypothesized interaction effect. From the remaining eligible students, 180 were randomly selected and assigned to four groups of 45 according to a 2 × 2 factorial design (game type: PSEG vs. PEG; interest level: high vs. low).

The sample size of 45 participants per group was determined a priori using G*Power 3.1 [33]. For a two-way ANCOVA design with one covariate testing the Game Type × Interest interaction, assuming a medium effect size ($f = 0.25$), $\alpha = 0.05$, and statistical power $(1 - \beta) = 0.80$, the minimum required total sample was 158 participants. After accounting for an anticipated attrition rate of approximately 10%–15% over the six-week intervention, we targeted 180 participants (45 per group). This group size also aligned with the natural class capacity at the participating institutions (≈ 45 students per cohort), ensuring ecological validity and practical feasibility within the regular course schedule.

All experimental sessions were conducted by the same instructor (male, lecturer rank, 8 years of teaching experience) to eliminate teacher-related confounding. The instructor followed a standardized script and used identical presentation materials across all groups. All sessions were conducted in computer laboratories with identical equipment and software configurations. The experimental and control groups followed the same schedule of three 45-minute sessions per week for six weeks. All participants provided informed consent. The study was approved by the institutional ethics committee and conducted in accordance with the Declaration of Helsinki.

4.3 Materials and Instruments

4.3.1 Photography Educational Games

Two 3D educational games were developed for this study: the Photography Simulation Educational Game (PSEG) and the Photography Educational Game (PEG). Both games were developed using Unity3D and Autodesk 3ds Max. They shared identical content, interface, tasks, and reward systems. The games covered four photography topics based on the textbook New Photography Notes: framing, exposure, depth of field, and composition. They featured four 3D scenes: a Chinese classical garden, a magic forest, a winter forest, and an ancient town. The 3D environments provided immersive contexts for students to apply photographic concepts in visually rich settings.

The design of both games operationalized the three theoretical frameworks in specific ways. First, consistent with CTML, photographic concepts (e.g., aperture, shutter speed, depth of field) were presented through dual channels: visual diagrams and animations accompanied by narrated explanations, reducing extraneous cognitive load and facilitating schema construction. Second, in line with DGBL, both games incorporated game mechanics such as point-based rewards, progressive task difficulty, and immediate performance feedback to sustain engagement and motivation. Third, and most importantly, ELT was operationalized exclusively in PSEG through its camera simulation function. In PSEG, students engaged in concrete experience by manipulating virtual camera parameters (aperture, shutter speed, focal length) and observing the resulting visual outcomes (framing range, depth of field, brightness) in real time. This was followed by reflective observation, as the game provided visual comparisons between the student's settings and optimal parameters. In contrast, PEG replaced this simulation with multiple-choice quizzes that assessed declarative knowledge of the same photographic concepts, thus providing no opportunity for experiential practice. This deliberate design choice—keeping CTML and DGBL features constant across both games while varying only the ELT-driven simulation component—allowed the study to isolate the unique contribution of simulation-based experiential learning to innovation skill development. Table 6 shows the mapping of theoretical frameworks to game design features and outcome measures. Figure 1 compares PSEG and PEG main interfaces in this study.

Table 6
Mapping of theoretical frameworks to game design features and outcome measures.

Theoretical Framework	Core Principle	Operationalization in PSEG	Operationalization in PEG	Associated Outcome Measure	Theoretical Framework
CTML (Mayer, 2009)	Dual-channel presentation; reduce extraneous cognitive load	Visual diagrams + animations + narrated explanations for aperture, shutter speed, depth of field	Same as PSEG	ISPS (self-reported perceived learning)	CTML (Mayer, 2009)
DGBL (Prensky, 2001)	Challenge, feedback, reward mechanics to sustain motivation	Point-based rewards, progressive task difficulty, immediate feedback	Same as PSEG	ISPS (self-reported engagement)	DGBL (Prensky, 2001)
ELT (Kolb, 1984)	Concrete experience → reflective observation → abstract conceptualization	Virtual camera simulation: real-time manipulation of aperture/shutter speed/focal length with immediate visual feedback	No virtual camera simulation	ISPT (performance-based photography output)	ELT (Kolb, 1984)

PSEG included a camera simulation function that PEG lacked. In PSEG, students could manipulate virtual camera parameters such as aperture, shutter speed, and focal length in real time. The simulation replicated three photographic effects: framing range, depth of field, and brightness. Framing range was controlled through camera distance and field of view. Depth of field was simulated using Gaussian and motion blur. Brightness was adjusted through color value processing. Students could observe the visual outcomes of their adjustments instantly. For assignments outside the game, students in both groups used real cameras. This design isolated the specific contribution of simulation features to learning outcomes while keeping all other variables constant. Figure 2 shows the shooting interface of PSEG.

4.3.2 Innovation Skills in Photography Survey (ISPS)

The ISPS was adapted from Huang's 29-item Scale of Photographic Creativity [18]. The original scale comprises seven factors. The present study selected five factors that align with the conceptualization of innovation skills as observable and learnable behaviors. These five factors are Environmental Theme Observation, Wisdom Concept Development, Use of Thinking Patterns, Photographic Knowledge Application, and Value Image. The other two factors (Personality Trait Exploration and Motivation Theme Establishment) were excluded because they measure relatively stable dispositions rather than learnable skills. This selection resulted in a 12-item instrument, with 3, 3, 2, 2, and 2 items per factor respectively.

The original scale used a 4-point Likert format. The present study adapted it to a 5-point scale. This change provided a neutral midpoint for respondents. It also maintained consistency with the response format used in other instruments within this study [31]. The ISPS consists of 12 items across five dimensions. Items are rated on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Total scores range from 12 to 60. The Cronbach's alpha for this scale was 0.815 in the pilot test [32], indicating good internal consistency.

4.3.3 Innovation Skills in Photography Test (ISPT)

The ISPT was developed based on Qin's [19] four-dimension framework (shooting subjects, overall expressiveness and originality, composition, and technique and execution). Each dimension was scored on a 5-point scale, yielding total scores from 4 to 20.

Students completed a photography assignment on the topic "Beautiful Moments" using real cameras at both pre-test and post-test (one photograph per student per time point).

Two trained evaluators, both holding master's degrees in photography with over five years of teaching experience, independently rated all photographs. Prior to rating, they attended a 3-hour training session to review the scoring rubric and calibrate judgments using 20 pilot photographs not included in the main study (Cohen's $\kappa = 0.78$). Photographs were randomized, and evaluators were blinded to students' group assignments and time points. Disagreements exceeding 1 point on any dimension (~ 8% of ratings) were resolved through consensus; otherwise, the average of the two ratings was used. The final inter-rater reliability was Cohen's $\kappa = 0.81$. All rating sessions were conducted independently.

4.3.4 Interests in Photography Survey (IPS)

The IPS was adapted from Luo et al. [16] to measure students' interest in photography. This survey was administered to all 400 students before the experiment began. The questionnaire consisted of 15 items rated on a 5-point Likert scale. Total scores ranged from 15 to 75.

Following the extreme-group classification described in Section 4.2, IPS scores of 15–35 were classified as low interest and scores of 55–75 as high interest; middle-range scores (36–54) were excluded. The IPS demonstrated good internal consistency (Cronbach's $\alpha = 0.82$) in the pilot test.

4.4 Procedure

Before the six-week intervention began, all students completed the IPS to determine their interest level (as described in Section 4.2). The experiment lasted six weeks. In the first week, students completed the pre-test assessments. The ISPS was administered online using Wenjuanxing, a Chinese survey platform. For the ISPT, students used real cameras to complete a photography assignment outside the game environment. After the pre-test, teachers introduced how to use the game to all students. It is worth noting that the two games served as supplementary learning tools throughout the course. They did not replace real camera equipment.

In the second to fifth weeks, students engaged in game-based learning activities once per week. Each session consisted of three 45-minute classes. The PSEG group used the simulation game, while the PEG group used the non-simulation game. Each group completed four topics (framing, exposure, depth of field, and composition) from week 2 to 5. In the sixth week, students completed the post-test assessments using the same procedures as the pre-test. The pre-test and post-test were separated by a six-week interval to minimize memory effects. Figure 3 illustrates the overall experimental procedure.

4.5 Data Analysis

All statistical analyses were conducted using SPSS version 27.0. Descriptive statistics (means and standard deviations) were computed for all variables. One-way analysis of covariance (ANCOVA) was used to compare post-test scores between the PSEG and PEG groups, controlling for pre-test scores. Two-way ANCOVA was used to examine the interaction effect between game type and interest level. Prior to ANCOVA, assumptions of normality, homogeneity of variance, homogeneity of regression slopes, and linearity were tested. Shapiro-Wilk tests were used for normality testing, and Levene's test was used for homogeneity of variance. Effect sizes (partial η^2) were reported and interpreted using Cohen's guidelines (where 0.01, 0.06, and 0.14 indicate small, medium, and large effects, respectively). The significance level was set at $p < 0.05$ for all statistical tests. All tests were two-tailed.

Abbreviations

ANCOVA	Analysis of Covariance
GBL	Game-Based Learning
DGBL	Digital Game-Based Learning
CTML	Cognitive Theory of Multimedia Learning
DMT	Digital Media Technology
ELT	Experiential Learning Theory
IPS	Interests in Photography Survey
ISPS	Innovation Skills in Photography Survey
ISPT	Innovation Skills in Photography Test
PEG	Photography Educational Game
PSEG	Photography Simulation Educational Game

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Jawatankuasa Etika Penyelidikan Manusia, Universiti Sains Malaysia (JEPeM-USM) (Approval No. USM/JEPeM/PP/25100821). All participants were informed about the purpose and procedures of the study prior to participation. Written informed consent was obtained from all participants. Participation was voluntary, and participants were assured of their right to withdraw at any time without penalty. All data were anonymized prior to analysis to ensure confidentiality.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form.

Availability of data and materials

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare no competing interests.

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Authors' contributions

Conceptualization, C.X. and W.A.J.W.Y. conceived and designed the study. C.X. developed the methodology and performed the formal analysis. C.X. and G.P. developed the software. C.X. conducted the investigation and curated the data. C.X. prepared the original draft. C.X. and W.A.J.W.Y. reviewed and edited the manuscript. C.X. visualized the data. W.A.J.W.Y. supervised the study. C.X. and W.A.J.W.Y. administered the project and acquired the funding. All authors have read and agreed to the published version of the manuscript.

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Figures

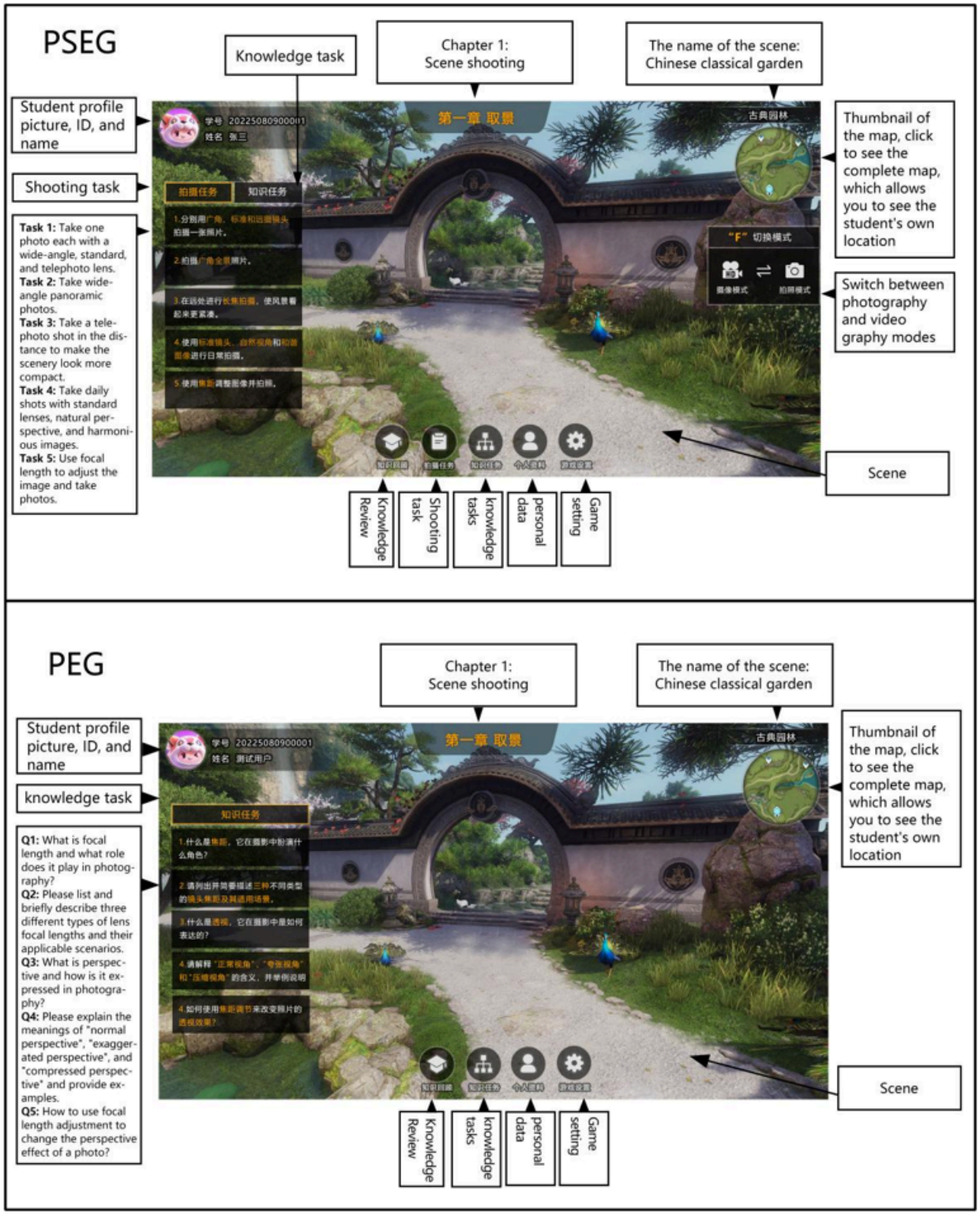


Figure 1

Comparison of PSEG and PEG main interfaces.

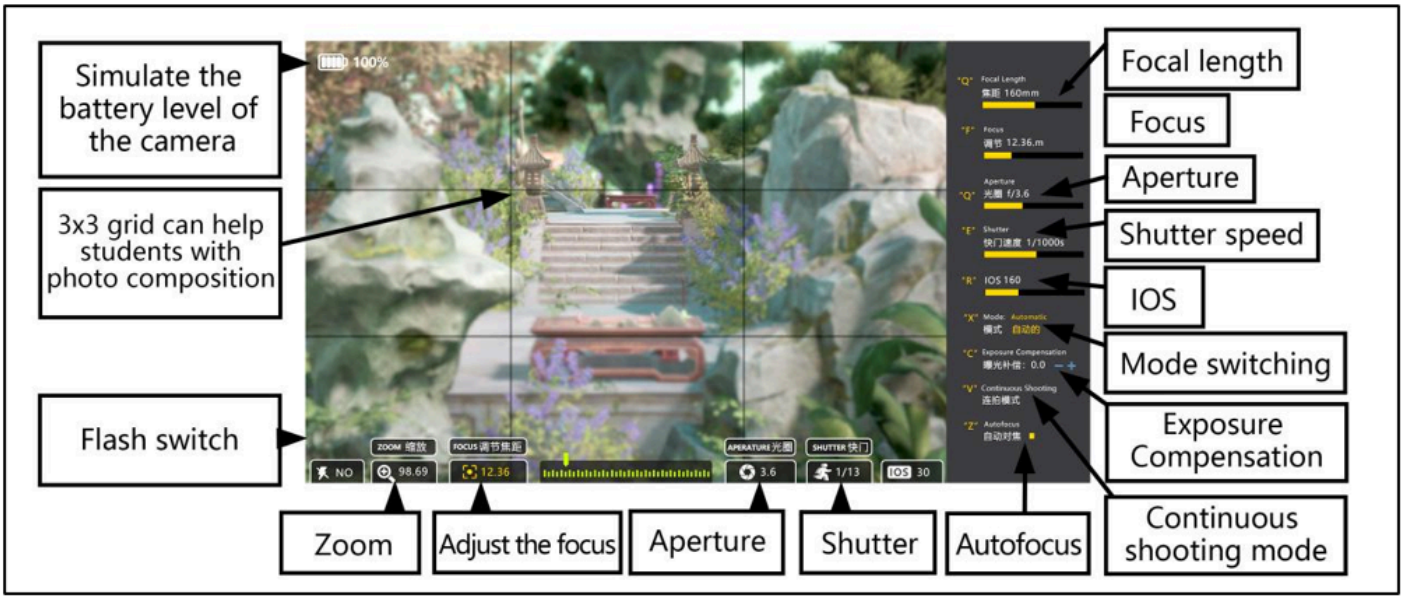


Figure 2

Shooting interface of PSEG.

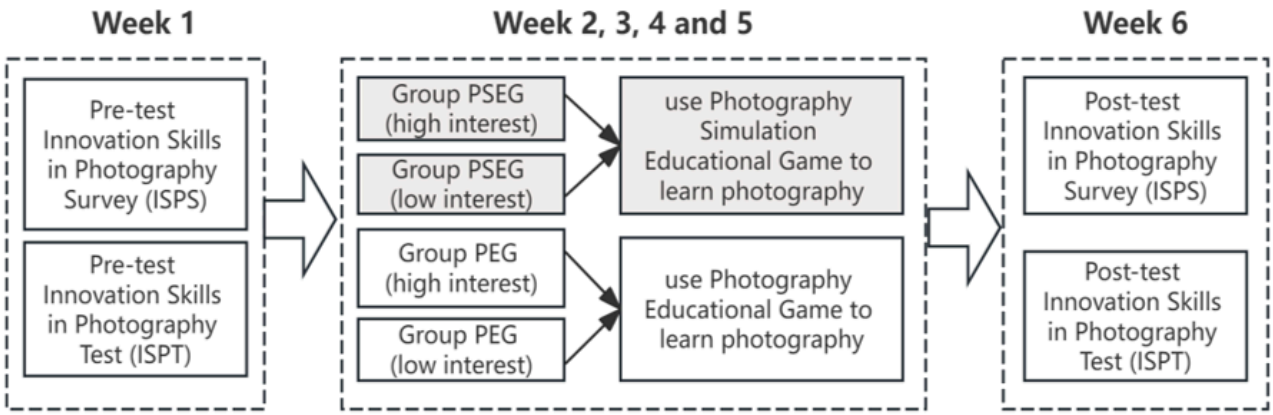


Figure 3

Overview of the experimental procedure across the six-week intervention period.