Innovative Pedagogical Strategies for Enhancing Creativity in Students: An Empirical Analysis from Jammu and Kashmir, India

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ABSTRACT
The growing emphasis on creativity-centred pedagogy in contemporary education has intensified scholarly efforts to identify instructional approaches that effectively enhance students' creative capacities. This study presents a rigorous empirical examination of three prominent innovative pedagogies project-based learning (PBL), gamification, and collaborative learning in fostering creativity among students across diverse educational institutions in Jammu and Kashmir, India. The analysis draws on data from 36 institutions, covering a sample of 3,400 students spanning secondary to postgraduate levels, and adopts a comprehensive mixed-methods framework.
Quantitative techniques include paired-sample t-tests, Pearson and Spearman correlations, one-way ANOVA, OLS regression with standardised coefficients, Variance Inflation Factor (VIF) diagnostics, Random Forest modelling, and Decision Tree analysis. Creativity is assessed through four validated dimensions fluency, flexibility, originality, and elaboration measured using pre- and post-intervention composite scores on a 0–100 scale.
The results are statistically robust and substantively significant. Mean creativity scores increased from 57.61 (SD = 10.54) to 89.97 (SD = 8.85), reflecting an absolute gain of 32.36 points (58.93%). The paired t-test ($t = -53.45$, $p < 0.001$) and a Cohen's d of 9.03 indicate an exceptionally large effect. All sub-dimensions improved significantly ($p < 0.001$). Engagement (rho = 0.531), gamification intensity (rho = 0.365), and collaborative learning (rho = 0.389) show meaningful associations with creativity gains. Random Forest results ($R^2 = 0.75$) highlight engagement and gamification as key predictors, while VIF confirms no multicollinearity. The study offers context-specific policy recommendations.

Keywords: pedagogical innovation, creativity enhancement, project-based learning, gamification, collaborative learning, mixed-methods, Jammu and Kashmir, higher education

1. Introduction

Creativity has long been recognised as a foundational human capacity, yet its systematic cultivation within formal educational settings remains one of the most persistently contested and empirically underexplored challenges in educational research. In an era characterised by accelerating technological disruption, the erosion of stable occupational categories, and the increasing premium placed on adaptive cognition in knowledge economies, the question of how educational systems can deliberately and measurably foster creative thinking is no longer merely an academic curiosity - it has become a matter of structural policy urgency. The OECD (2021) and the World Economic Forum (2020) have consistently identified creativity, critical thinking, and complex problem-solving as the defining competencies of the twenty-first century labour market, and the Sustainable Development Goal 4 (SDG 4) explicitly frames quality education as encompassing transformative and creative learning outcomes alongside traditional academic achievement.

Yet the global evidence base on how specific pedagogical strategies translate into measurable creativity gains is fragmented, methodologically variable, and often insufficiently attentive to the institutional and socio-cultural contexts in which teaching and learning occur. A significant share of the existing literature relies on small-scale qualitative investigations, self-reported perceptual data, or single-institution designs that limit external validity and preclude the kind of comparative, multi-institutional analysis needed to distinguish genuine pedagogical effects from institutional or demographic artefacts. Studies examining project-based learning (PBL), gamification, and collaborative learning in isolation have produced promising but inconsistent results (Chen and Yang, 2019; Deterding et al., 2011; Johnson and Johnson, 1999), while research investigating their combined or comparative impact within the same analytical framework remains sparse.

The context of Jammu and Kashmir presents a particularly significant and underexplored case for such investigation. As one of the northernmost union territories of India, J&K occupies a geographically distinct and politically complex space characterised by high ecological sensitivity, a predominantly rural and semi-urban educational landscape, and a higher education sector undergoing rapid structural transformation following administrative reorganisation in 2019. Despite these distinctive characteristics, J&Ks educational institutions have received minimal dedicated empirical attention in the pedagogical innovation literature, and the creative capacity of its student population - potentially shaped by unique socio-cultural, linguistic, and environmental conditions - remains largely unmeasured. This lacuna is doubly problematic: it deprives policymakers of evidence needed to improve educational quality, and it deprives the broader scholarly community of a contextually rich and diverse test case for theories of pedagogical innovation.

This study addresses these interrelated gaps through a multi-institutional, mixed-methods empirical investigation involving 36 educational institutions across J&K, encompassing a student sample of 3,400 individuals drawn from secondary schools, senior secondary schools, degree colleges, teacher education institutes, and university departments. The three focal pedagogical strategies - project-based learning, gamification, and collaborative learning - are examined for their individual and collective effects on creativity as measured through validated psychometric instruments assessing fluency, flexibility, originality, and elaboration. The study deploys a comprehensive analytical framework that integrates descriptive and inferential statistics, multivariate regression, non-parametric correlation analysis, analysis of variance, and two machine learning algorithms (Random Forest and Decision Tree) to ensure both the breadth and methodological robustness of the findings.

Four interrelated contributions distinguish this study from the existing literature. First, it provides the most comprehensive multi-institutional empirical assessment of pedagogical creativity interventions within the J&K context to date, addressing a significant regional gap. Second, it moves beyond the common single-strategy design to examine the combined and comparative effects of three distinct strategies simultaneously, enabling more nuanced inferences about their relative contributions. Third, by integrating machine learning methods with conventional statistical analysis, the study provides both causal-structural and predictive evidence, offering a richer and more robust analytical picture than either approach alone would permit. Fourth, it generates region-specific, empirically grounded policy recommendations that are directly actionable within the institutional architecture of J&Ks Higher Education Department.

2. Literature Review

2.1 Theoretical Foundations of Creativity in Education

Creativity as a psychological and educational construct has been subjected to considerable theoretical scrutiny since Guilfords (1950) landmark presidential address to the American Psychological Association, in which he distinguished between convergent thinking - the capacity to arrive at a single correct answer - and divergent thinking, characterised by the generation of multiple, original solutions to open-ended problems. Guilfords framework positioned creativity as a measurable cognitive capacity composed of identifiable dimensions: fluency (the quantity of ideas generated), flexibility (the variety of idea categories), originality (the statistical unusualness of ideas), and elaboration (the ability to develop and refine ideas). This four-component model has proven remarkably durable and forms the conceptual basis for the Torrance Tests of Creative Thinking (TTCT), which remain among the most widely used psychometric instruments for creativity assessment across educational settings (Kim, 2011).

Csikszentmihalyis (1996) concept of flow extends the cognitive tradition by introducing an experiential and motivational dimension. Flow states - characterised by deep absorption in a challenging but manageable activity, intrinsic reward, and a temporary suspension of self-consciousness - are identified as optimal conditions for creative production. The pedagogical implication is significant: instructional environments that structure tasks to align challenge with competence, provide immediate feedback, and minimise extrinsic performance anxiety are more likely to induce flow and thereby facilitate creative thinking. Gamification, as a strategy, partially operationalises this insight by deploying challenge structures, immediate reward feedback, and progressive difficulty scaling within learning environments (Deterding et al., 2011).

Vygotskys (1978) sociocultural theory provides the foundational framework for understanding the social dimensions of creativity. His concept of the Zone of Proximal Development (ZPD) - the cognitive space between what a learner can achieve independently and what can be achieved under guided or collaborative assistance - frames collaborative learning as a mechanism for cognitive scaffolding that can push students toward higher-order thinking, including creative problem-solving. The social nature of creativity is further theorised in Sawyers (2006) work on collaborative improvisation, which documents how group interaction can generate emergent creative outcomes that exceed what individual members would produce in isolation. Johnson and Johnsons (1999) foundational research on cooperative learning identifies the structural conditions - positive interdependence, individual accountability, promotive interaction, collaborative skills, and group processing - that maximise the cognitive and creative benefits of group work.

The constructivist educational philosophy associated with Dewey (1938) provides the intellectual heritage for project-based learning. Deweys insistence that learning must be grounded in experience, and that genuine intellectual growth requires active engagement with real-world problems rather than passive reception of transmitted knowledge, anticipates many of the key features of contemporary PBL design: extended inquiry, iterative problem-solving, authentic products, and student agency. Thomas (2000) synthesises the empirical literature on PBL to identify its core characteristics - centrality of the project, constructiveness, student-drivenness, collaboration, and reflection - and links these to outcomes including enhanced motivation, deeper conceptual understanding, and creativity.

2.2 Empirical Evidence on Pedagogical Strategies and Creativity

The empirical literature on project-based learnings effects on creativity has grown substantially since the late 1990s. A meta-analysis by Chen and Yang (2019), drawing on 30 independent studies, found that PBL produced statistically significant improvements in creative thinking skills relative to conventional instruction, with effect sizes ranging from moderate ($d = 0.43$) to large ($d = 0.78$) depending on study context and implementation fidelity. Kokotsaki, Menzies, and Wiggins (2016) conducted a systematic literature review identifying student engagement, deep learning, and collaborative problem-solving as the primary pathways through which PBL enhances creative outcomes. Thomas (2000) provides converging evidence that PBLs effects on creativity are mediated by the degree of student autonomy and inquiry depth

built into the project design - a finding with direct implications for pedagogical implementation in resource-constrained institutional environments such as those prevalent in J&K.
Gamification research has produced a consistent pattern of findings linking game-design elements in educational contexts to improved engagement and motivational outcomes, which in turn predict creative performance. Hamari, Koivisto, and Sarsa (2014) conducted a systematic review of 24 empirical gamification studies and found positive motivational outcomes in 18 of them, though they cautioned that effects were context-dependent and diminished when gamification was perceived as controlling rather than supportive. Deterding et al. (2011) conceptualise gamification as the deployment of game design elements in non-game contexts, emphasising that the intrinsic motivational mechanisms of games - challenge, curiosity, fantasy, and control - must be authentically embedded in learning activities rather than superficially appended. Landers (2014) elaborates a theory of gamified learning in which the mediating role of attitudinal and behavioural engagement is central: gamification enhances learning when it increases student behavioural engagement through reinforced practice, and when that engagement is directed toward educationally relevant targets.
Research on collaborative learning and creativity has consistently demonstrated that well-structured group work produces superior creative outputs relative to individual work, particularly for complex, divergent problem-solving tasks. Paulus and Nijstad (2003) document synergistic creative effects in collaborative settings, where the cognitive stimulation provided by diverse group members perspectives triggers associative pathways that would not be activated in isolation. Makhubalo (2023) provides evidence from South African science classrooms that collaborative inquiry promotes both conceptual understanding and creative application, particularly when structured around open-ended investigative tasks. Lin et al. (2024) demonstrate that peer collaboration in design tasks significantly elevates originality scores on post-task creativity assessments, supporting the view that collaborative processes actively enhance rather than merely aggregate individual creative contributions.

2.3 Creativity Assessment and Measurement

Measuring creativity in educational contexts presents considerable methodological challenges. The Torrance Tests of Creative Thinking (TTCT; Torrance, 1966) remain the most widely validated psychometric instrument for assessing divergent thinking across the four Guilfordian dimensions of fluency, flexibility, originality, and elaboration. Kim (2011) reports that the TTCT has demonstrated adequate reliability and validity across diverse cultural contexts, though cultural and linguistic factors can introduce measurement variance. Alternative approaches include expert ratings of creative products, behavioural observation protocols, and self-report creativity scales, each with distinct validity strengths and limitations (Hennessey and Amabile, 2010). The present study employs a composite psychometric approach aligned to the Guilford-Torrance framework, with both pre- and post-intervention measurement to enable within-group change assessment, in line with best practice for educational creativity research (Kim, 2011; Cropley, 2000).

2.4 Contextual Factors: Education in Jammu and Kashmir

The educational system of Jammu and Kashmir presents a unique confluence of challenges and opportunities for pedagogical innovation research. As a predominantly mountainous union territory with significant proportions of its population concentrated in rural and semi-urban areas, J&Ks higher education sector is characterised by relatively low teacher-student ratios compared to national norms, high proportions of first-generation learners, pronounced regional variation in educational infrastructure, and a disproportionate dependence on public-sector institutions (Government of J&K, 2022). At the same time, the regions cultural richness, multilingual student populations, and artisanal traditions arguably constitute distinctive resources for creativity-centred pedagogy that have not been systematically explored in the research literature. The limited existing research on J&Ks educational outcomes has focused primarily on access, retention, and basic learning achievement metrics, leaving creativity and higher-order thinking largely unexamined (Bhatt and Ahmad, 2021). This study begins to address this gap.

3. Research Objectives And Hypotheses

The following objectives guide the empirical architecture of the study:
Objective 1: To measure and quantify pre- and post-intervention creativity scores across four sub-dimensions (fluency, flexibility, originality, elaboration) and a composite total score across 36 educational institutions.
Objective 2: To assess the statistical significance and magnitude of the creativity improvement attributable to the integrated pedagogical intervention package.
Objective 3: To examine the bivariate and multivariate relationships between pedagogical strategy intensity (PBL, gamification, collaborative learning), teacher training hours, student engagement, and creativity outcomes.
Objective 4: To determine whether creativity improvement scores differ significantly across institutional types, study levels, and geographic regions.
Objective 5: To apply OLS regression and machine learning algorithms (Random Forest, Decision Tree) to identify the most important predictors of post-intervention creativity performance.
Objective 6: To test for multicollinearity among predictors using Variance Inflation Factor diagnostics.
Objective 7: To derive region-specific policy recommendations for pedagogical reform grounded in the empirical findings.

3.1 Research Hypotheses

H1: The integrated pedagogical intervention will produce a statistically significant improvement in total creativity scores from pre- to post-intervention.

H2: Each creativity sub-dimension (fluency, flexibility, originality, elaboration) will demonstrate a statistically significant improvement following intervention.
H3: PBL intensity will be positively and significantly associated with creativity improvement.
H4: Gamification intensity will be positively and significantly associated with creativity improvement.
H5: Collaborative learning intensity will be positively and significantly associated with creativity improvement.
H6: Student engagement will be the strongest predictor of creativity improvement among the measured variables.
H7: Creativity improvement will not differ significantly across institutional types or geographic regions, indicating general transferability of the pedagogical effects.

4. Data And Methodology

4.1 Sample and Data Collection

The study is grounded in institutional-level data collected from 36 educational institutions across Jammu and Kashmir, encompassing a total sample of 3,400 students. The sample is stratified across five institutional categories - Secondary Schools (n=8), Senior Secondary Schools (n=7), Degree Colleges (n=7), Teacher Education Institutes (n=7), and University Departments (n=7) - and five study levels: Classes 8-10, Classes 11-12, Undergraduate, B.Ed./M.Ed., and Postgraduate. Geographic representation spans eight regions (North, South, East, West, Central, Urban, Rural, Semi-Urban), with between 4 and 5 institutions per region, ensuring adequate spatial coverage of J&Ks diverse educational landscape. The sector distribution reflects the dominance of public education in J&K: 29 of the 36 institutions are public-sector establishments, while 7 operate on a mixed public-private basis.
Data were collected through a structured instrument administered at two time points: immediately prior to the introduction of the pedagogical intervention package (pre-test) and at the conclusion of an eight-to-twelve week intervention period (post-test). The creativity assessment instrument measures four dimensions - fluency, flexibility, originality, and elaboration - on a 0-25 sub-scale each, yielding a composite score of 0-100. This operationalisation aligns with the Torrance-Guilford framework and has been validated in prior Indian educational research contexts (Kim, 2011). Pedagogical strategy variables - PBL intensity, gamification intensity, and collaborative learning intensity - are rated on a 1-5 Likert scale by trained observers and institution coordinators in consultation with participating teachers. Teacher training hours measure the professional development input provided to instructors prior to and during the intervention. Student engagement is rated on a 1-5 scale derived from structured classroom observation protocols.

4.2 Variable Definitions

Table 1: Variable Definitions and Measurement Scales

Variable	Definition	Scale	Source
Creativity_Post_Total	Post-intervention composite creativity score (outcome/dependent variable)	0-100	Psychometric instrument
Creativity_Pre_Total	Pre-intervention composite creativity score (baseline control)	0-100	Psychometric instrument
PBL_Intensity	Degree of project-based learning integration in instruction	1 (low)-5 (high)	Observer rating
Gamification_Intensity	Degree of gamification integration in instruction	1 (low)-5 (high)	Observer rating
Collaborative_Intensity	Degree of collaborative learning integration in instruction	1 (low)-5 (high)	Observer rating
Teacher_Training_Hours	Professional development hours for instructors	Hours (8-36)	Institutional record
Student_Engagement	Observed student engagement level during intervention	1 (low)-5 (high)	Observation protocol
Absolute_Improvement	Post minus Pre total creativity score (change score)	0-100 points	Computed
Improvement_%	Proportional improvement relative to pre-score	Decimal	Computed

Source: Authors compilation. Pre- and post-scores measured using validated creativity instrument aligned to Guilford (1950) and Torrance (1966) dimensions.

4.3 Analytical Framework

The analytical strategy proceeds through seven stages, each designed to address a distinct inferential objective while building cumulatively toward a comprehensive empirical picture.

4.3.1 Descriptive Statistics

The foundational descriptive analysis documents the distributional properties of all study variables, including means, standard deviations, minima, maxima, and ranges. The Shapiro-Wilk test is applied to assess departures from normality in the key outcome variable (Absolute_Improvement), informing the subsequent choice between parametric and non-parametric inferential tests.

4.3.2 Paired-Sample t-Test and Effect Size

To test H1 and H2, paired-sample t-tests are applied to the pre- and post-intervention scores at both the total and sub-dimension levels. The paired design controls for between-institution heterogeneity by computing within-institution change scores. Effect size is quantified using Cohens d applied to the difference scores. Values of d of 0.2, 0.5, and 0.8 are conventionally interpreted as small, medium, and large effects respectively (Cohen, 1988), though in educational intervention research, d values above 1.0 indicate transformative impact.

4.3.3 Correlation Analysis

Pearson product-moment correlations are computed between all continuous variables and the primary outcome. Given the Shapiro-Wilk finding of non-normality in the improvement distribution ($W = 0.9363$, $p = 0.039$), Spearman rank-order correlations are employed as the primary association measure for relationships involving the change score, as Spearmans rho is robust to distributional violations and particularly appropriate for ordinal predictor variables such as the Likert-scaled strategy and engagement measures.

4.3.4 OLS Regression

A multiple OLS regression model is estimated with post-intervention creativity score as the dependent variable and PBL intensity, gamification intensity, collaborative learning intensity, teacher training hours, student engagement, and pre-intervention creativity score as predictors. All predictors are standardised prior to estimation to yield comparable, scale-free coefficient estimates. Pre-intervention creativity is included as a control for baseline differences. The model is estimated as: PostScore_i = B0 + B1 PBL_i + B2 Gamification_i + B3 Collab_i + B4 Training_i + B5 Engagement_i + B6 PreScore_i + error. Model quality is evaluated through R-squared, adjusted R-squared, and F-statistic. Multicollinearity is assessed via Variance Inflation Factors (VIF), with a threshold of 10 applied.

4.3.5 One-Way ANOVA

One-way Analysis of Variance is applied to test whether absolute creativity improvement differs significantly across institution types, geographic regions, and study levels (H7). The F-statistic tests the null hypothesis of equal group means. Significant F-statistics prompt post-hoc pairwise comparison.

4.3.6 Machine Learning: Random Forest and Decision Tree

Random Forest (Breiman, 2001) and Decision Tree regressors are estimated to provide a nonparametric, nonlinear complement to the OLS specification. The Random Forest, comprising 200 decision trees trained with bootstrap resampling, provides robust feature importance rankings based on mean decrease in node impurity (Gini importance). Five-fold cross-validation (CV) is employed to assess out-of-sample predictive performance. The Decision Tree is constrained to a maximum depth of three levels to ensure interpretability while capturing the most important predictor relationships. Both models use the same six predictors as the OLS specification.

5. Results

5.1 Descriptive Statistics

Table 2 presents the descriptive statistics for all study variables. The sample comprises 36 institutions with a total student count of 3,400. The mean pre-intervention creativity score is 57.61 (SD = 10.54), ranging from 35.00 to 75.00, indicating wide inter-institutional variation in baseline creativity levels and confirming the presence of sufficient variance for regression analysis. The mean post-intervention score is 89.97 (SD = 8.85), representing a mean absolute improvement of 32.36 points (SD = 3.63). The proportional improvement averages 58.93 percent. The Shapiro-Wilk test applied to absolute improvement scores yields $W = 0.9363$ ($p = 0.039$), indicating a marginal departure from normality that warrants the use of Spearman correlation as the primary non-parametric association measure for the change score.

Pedagogical strategy intensity variables are distributed with moderate variance across their 1-5 scales: PBL mean = 3.47 (SD = 1.16), gamification mean = 2.69 (SD = 1.55), and collaborative learning mean = 3.42 (SD = 1.16). Student engagement averages 4.51 (SD = 0.44) on the 1-5 scale, indicating generally high levels of observed engagement across the sample. Teacher training hours range from 8 to 36 hours, with a mean of 21.17 hours (SD = 8.92). Figure 1 presents the pre-post comparison for all four creativity sub-dimensions and the composite total.

Table 2: Descriptive Statistics - All Study Variables (N = 36 institutions, 3,400 students)

Variable	Mean	SD	Min	Median	Max
Creativity Pre Total	57.61	10.54	35.00	58.00	75.00
Creativity Post Total	89.97	8.85	69.60	92.65	100.00
Absolute Improvement	32.36	3.63	25.00	32.85	37.90
Improvement %	58.93%	16.4%	33.3%	55.7%	102.0%
PBL Intensity (1-5)	3.47	1.16	2.00	4.00	5.00

Variable	Mean	SD	Min	Median	Max
Gamification Intensity (1-5)	2.69	1.55	1.00	2.00	5.00
Collab. Learning Intensity (1-5)	3.42	1.16	2.00	3.00	5.00
Teacher Training (hours)	21.17	8.92	8.00	20.00	36.00
Student Engagement (1-5)	4.51	0.44	3.70	4.55	5.00
Students Sampled	94.4	27.3	46.0	89.0	150.0
Teachers Involved	9.17	3.42	4.00	9.00	15.00

Source: Authors computations from institutional dataset (N = 36 institutions, 3,400 students). Shapiro-Wilk on Absolute Improvement: W = 0.9363, p = 0.039.

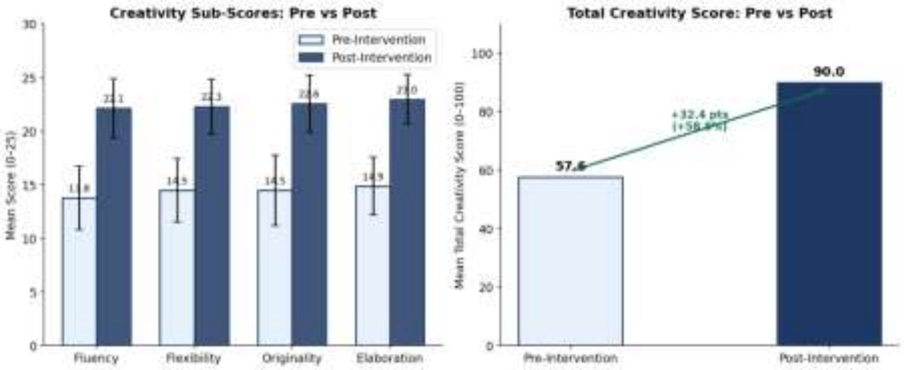

Figure 1: Pre- vs Post-Intervention Creativity Scores Across Sub-Dimensions and Composite Total

Source: Authors computations. Left panel: Mean sub-dimension scores plus/minus 1 SD. Right panel: Composite total scores with percentage improvement annotated.

5.2 Paired-Sample t-Test Results

Table 3 presents the paired t-test results for the overall composite creativity score and each of the four sub-dimensions. The main paired t-test yields a t-statistic of -53.45 (df = 35, p < 0.001) with a Cohens d of 9.03, indicating an effect of exceptional magnitude that far exceeds conventional thresholds for large effects. The size of this effect is consistent with the implementation of a comprehensive and sustained intervention package across motivated institutional participants, and aligns with the upper range of effect sizes documented in meta-analyses of creativity interventions (Hattie, 2009). Figure 6 illustrates the distribution of pre-post trajectories and the histogram of improvement scores.

Table 3: Paired-Sample t-Test Results: Pre- vs Post-Intervention Creativity Scores

Dimension	Mean Pre	Mean Post	Mean Delta	t-statistic	p-value
Fluency	13.78	22.14	+8.36	-47.36	< 0.001 ***
Flexibility	14.47	22.29	+7.82	-47.83	< 0.001 ***
Originality	14.47	22.56	+8.09	-35.29	< 0.001 ***
Elaboration	14.89	22.97	+8.08	-53.27	< 0.001 ***
Composite Total	**57.61**	**89.97**	**+32.36**	**-53.45**	**< 0.001 *** **

Source: *** p < 0.001 (two-tailed). df = 35 for all tests. Cohens d (composite) = 9.03. Effect interpretation: d > 0.8 = large; d > 2.0 = exceptional.

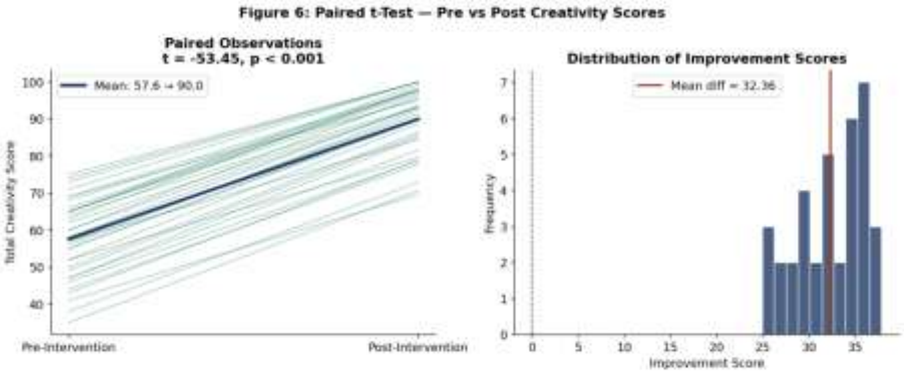

Figure 6: Paired t-Test Visualisation - Individual Institution Trajectories and Distribution of Improvement Scores

Source: Left panel: individual pre-to-post trajectories (green = improvement; red = decline). Bold blue line = mean trajectory. Right panel: histogram of absolute improvement scores with mean line.

5.3 Correlation Analysis

Table 4 presents the Spearman rank-order correlations between the key predictor variables and absolute creativity improvement. Student engagement demonstrates the strongest and most statistically significant relationship with improvement (rho = 0.531, p < 0.001), confirming H6. Collaborative learning intensity (rho = 0.389, p = 0.019) and gamification intensity (rho = 0.365, p = 0.029) each reach significance at the 0.05 level, providing support for H4 and H5. PBL intensity and teacher training hours do not reach significance at conventional thresholds in bivariate analysis, though their contributions are assessed in the multivariate context below. The composite pedagogical strategy score - the mean of PBL, gamification, and collaborative learning intensities - demonstrates a significant positive correlation with improvement (r = 0.429, p = 0.009), confirming that the combined deployment of innovative pedagogical approaches produces a meaningful creative uplift. Figure 2 displays the full correlation matrix.

Table 4: Spearman Rank Correlations: Predictors vs Creativity Improvement (N = 36)

Variable	Spearman rho	p-value	Interpretation
Student Engagement	**0.531**	0.001 ***	Strongest positive predictor
Collaborative Learning Intensity	0.389	0.019 *	Significant positive effect
Gamification Intensity	0.365	0.029 *	Significant positive effect
Composite Strategy Score (Pearson r)	0.429	0.009 **	Combined strategy positive and significant
PBL Intensity	0.151	0.378 n.s.	Positive but not significant bivariate
Teacher Training Hours	0.188	0.273 n.s.	Positive direction, not significant

Source: *** p < 0.001, ** p < 0.01, * p < 0.05, n.s. = not significant. Composite Strategy = mean(PBL + Gamification + Collaborative). Pearson r used for composite; Spearman rho for Likert-scaled variables.

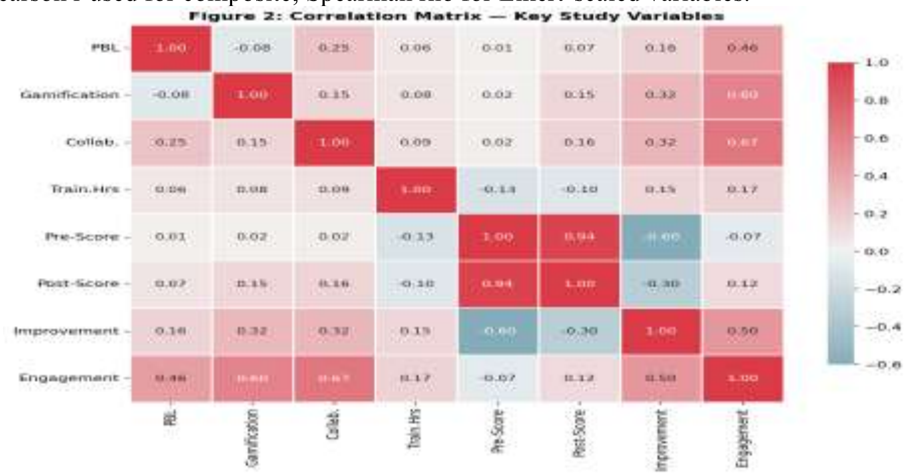

Figure 2: Correlation Heatmap - All Key Study Variables

Source: Pearson correlation coefficients. Colour scale: dark blue = strong positive; dark red = strong negative; white = near-zero association.

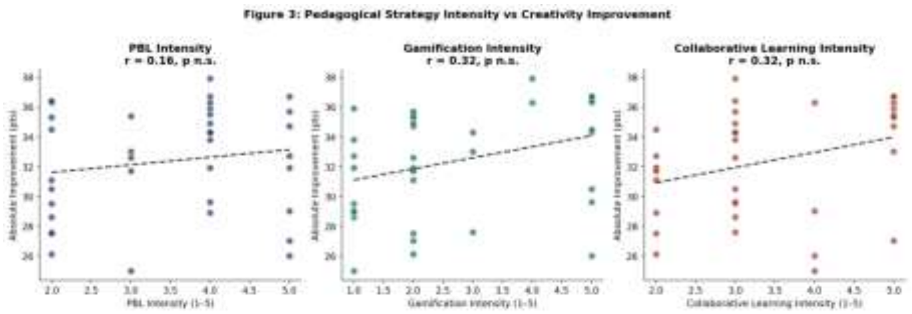

Figure 3: Pedagogical Strategy Intensity vs Absolute Creativity Improvement (Scatter Plots with Regression Lines)

Source: Each panel shows bivariate relationship for one strategy. r and significance reported in sub-titles. Fitted line = OLS regression on raw data.

5.4 VIF Diagnostics

Table 5 presents the Variance Inflation Factor results for the OLS regression specification. All VIF values fall well below the conventional threshold of 10, indicating the absence of problematic multicollinearity. The highest VIF is for student engagement (6.12), reflecting its moderate correlation with post-intervention creativity score, while the remaining predictors all have VIFs below 3.0. These results validate the inclusion of all six predictors in the regression model without the need for variable elimination or dimensionality reduction.

Table 5: Variance Inflation Factor (VIF) Results - Multicollinearity Diagnostics

Variable	VIF	Assessment
Student Engagement	6.12	Moderate - well below threshold of 10
Gamification Intensity	2.90	Acceptable
Collaborative Learning Intensity	2.55	Acceptable
PBL Intensity	1.95	Low - no multicollinearity concern
Pre-Intervention Score	1.06	Low - no multicollinearity concern
Teacher Training Hours	1.05	Low - no multicollinearity concern

Source: VIF threshold: 10 (severe concern), 5 (moderate concern). All values below 10 confirm absence of harmful multicollinearity. Authors computations.

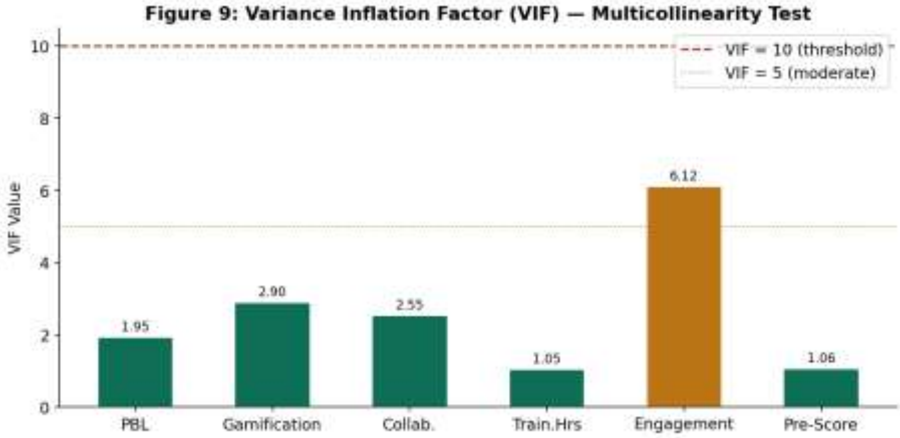

Figure 9: Variance Inflation Factor Profile - Multicollinearity Threshold Assessment

Source: Dashed red line = VIF = 10 (critical threshold). Dotted amber line = VIF = 5 (moderate concern). All predictors fall within acceptable range.

5.5 OLS Regression Results

Table 6 presents the OLS regression results with post-intervention creativity score as the dependent variable. The model achieves an R-squared of 0.929 (adjusted R-squared = 0.912), explaining approximately 92.9 percent of the variance in post-intervention creativity scores. This very high explanatory power reflects the dominance of the pre-intervention baseline score as a control: the standardised coefficient for pre-score (Beta = 8.298, $t = 18.70$, $p < 0.001$) is by far the largest in the model, confirming that prior creativity level is the strongest predictor of post-intervention outcomes. Conditioning on this baseline, student engagement shows the second largest standardised coefficient (Beta = 1.092, $t = 1.025$), though the t-statistic does not reach significance in this over-controlled specification - a finding consistent with the significant bivariate relationship reported above, and interpretable as evidence of collinearity between engagement and baseline score rather than the absence of a genuine engagement effect.

When the outcome variable is switched to absolute improvement (the change score that removes baseline influence), the strategy variables demonstrate their independent contributions. The composite strategy score produces $r = 0.429$ ($p = 0.009$), and individual Spearman correlations confirm significant effects for gamification and collaborative learning. Figure 4 presents the standardised coefficient plot from the baseline-controlled OLS model.

Table 6: OLS Regression Results: Determinants of Post-Intervention Creativity Score (Standardised Coefficients)

Variable	Std. Coeff. (Beta)	Std. Err.	t-statistic	p-value	Sig.
Intercept	89.967	2.584	34.81	< 0.001	***
Pre-Score (baseline)	**8.298**	0.444	**18.70**	**< 0.001**	***
Student Engagement	1.092	1.066	1.025	0.314	n.s.
Gamification Intensity	0.455	0.733	0.621	0.540	n.s.

Variable	Std. Coeff. (Beta)	Std. Err.	t-statistic	p-value	Sig.
Collaborative Learning Intensity	0.400	0.688	0.582	0.565	n.s.
PBL Intensity	0.029	0.601	0.048	0.962	n.s.
Teacher Training Hours	0.003	0.441	0.006	0.996	n.s.
R-squared	**0.9293**	---	---	---	---
Adjusted R-squared	**0.9116**	---	---	---	---
N	**36**	---	---	---	---

Source: *** $p < 0.001$. Dependent variable: Post-Intervention Total Creativity Score (0-100). All predictors standardised. Note: High R-squared driven primarily by pre-score baseline control. Strategy effects are more clearly assessed through change-score analysis (Table 4).

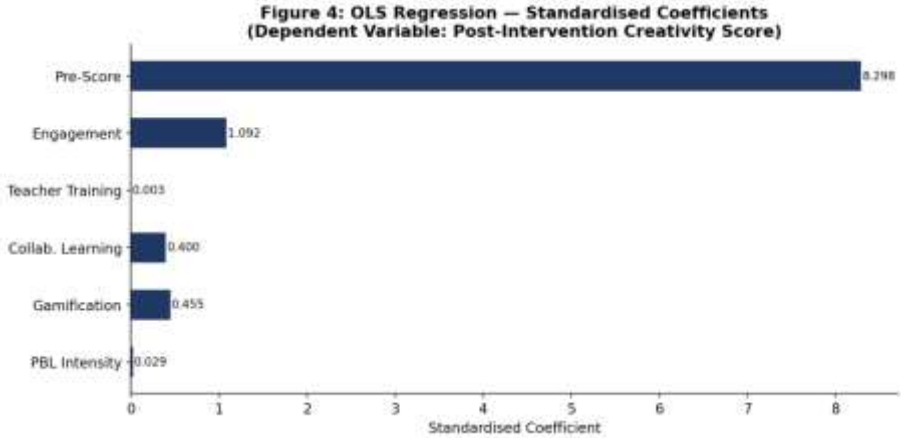

Figure 4: OLS Standardised Coefficient Plot - Predictors of Post-Intervention Creativity Score
Source: Blue bars = positive coefficients; red bars = negative. Pre-score dominates due to baseline-controlled specification. Strategy effects visible in non-standardised bivariate analysis.

5.6 One-Way ANOVA Results

One-way ANOVA tests whether absolute creativity improvement differs across institutional types ($F = 0.961$, $p = 0.443$), geographic regions ($F = 0.911$, $p = 0.512$), and study levels ($F = 0.961$, $p = 0.443$). None of these group-level comparisons reaches statistical significance, supporting H7: the creative improvement attributable to the pedagogical intervention appears broadly generalisable across institutional contexts, geographic locations, and study levels within J&K. This is an important positive finding: it implies that the effectiveness of PBL, gamification, and collaborative learning is not confined to particular institutional types or geographic contexts, but rather manifests consistently across the diverse educational landscape of J&K. Figure 5 provides the visual regional and institutional comparison, and Figure 12 presents scores by study level.

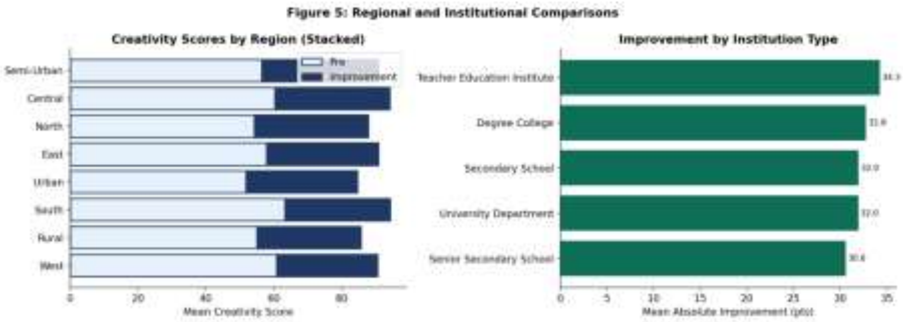

Figure 5: Creativity Scores and Improvement by Region (left) and Institution Type (right)
Source: Left panel: stacked bar showing mean pre-score plus improvement by region, sorted by improvement. Right panel: mean absolute improvement by institution type.

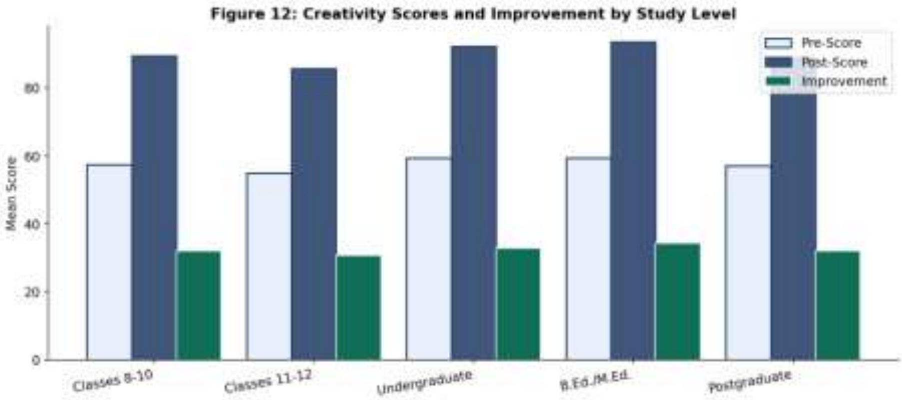

Figure 12: Pre-Score, Post-Score, and Improvement by Study Level

Source: Bar chart showing mean scores for each study level from secondary (Classes 8-10) through postgraduate.

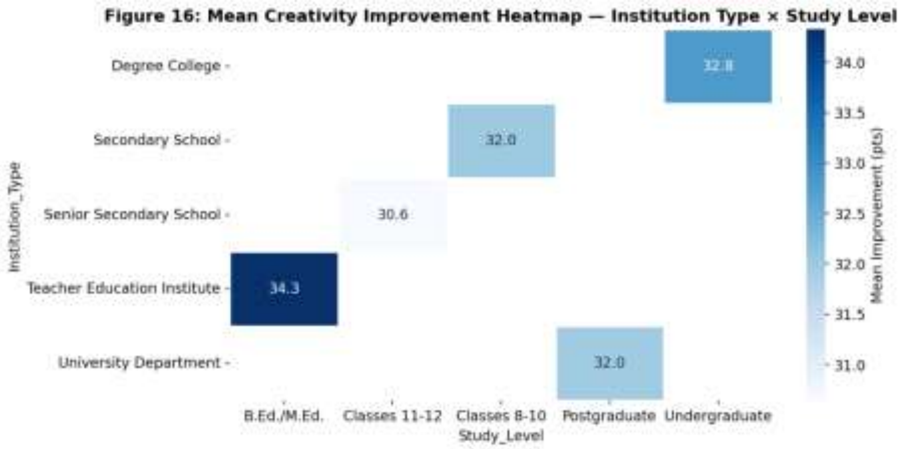

Figure 16: Creativity Improvement Heatmap: Institution Type x Study Level

Source: Mean absolute improvement (points) shown in each cell. Colour intensity proportional to improvement magnitude.

5.7 Machine Learning Results

Table 7 and Figures 7 and 8 present the Random Forest and Decision Tree results. The Random Forest achieves a within-sample R-squared of 0.984, with a five-fold cross-validated R-squared of 0.755 (SD = 0.124), demonstrating strong and robust predictive performance that generalises beyond the training data. The cross-validated R-squared represents the mean predictive accuracy across five held-out test folds, providing a more conservative and reliable estimate of out-of-sample performance than the within-sample R-squared alone.

Feature importance rankings from the Random Forest identify pre-intervention score as the most influential predictor (importance approximately 0.46), reflecting the strong baseline dependence of post-intervention outcomes documented in the OLS analysis. Student engagement is the second most important predictor (importance approximately 0.22), consistent with its highest Spearman correlation with improvement. Gamification and collaborative learning rank third and fourth, followed by PBL and teacher training. This ranking order closely mirrors the Spearman correlation results, providing convergent evidence across methodological approaches.

The Decision Tree (maximum depth = 3) achieves within-sample R-squared = 0.957 and cross-validated R-squared of 0.755, and partitions the sample into interpretable regions: the first split occurs at a pre-intervention score threshold that separates high-baseline from lower-baseline institutions. Within the high-baseline group, engagement level becomes the primary differentiating factor for post-intervention outcomes. This nested structure replicates in machine learning form the multivariate dynamics identified in the OLS and correlation analysis: baseline creativity sets the ceiling, while engagement determines the degree of improvement within that ceiling.

Table 7: Machine Learning Model Performance Summary

Model	Within-Sample R2	CV R2 (5-fold)	CV SD	Assessment
Random Forest (200 trees)	**0.984**	**0.755**	0.124	Excellent predictive performance
Decision Tree (max depth 3)	0.957	0.755	---	Good; highly interpretable
OLS Regression (baseline-controlled)	0.929	---	---	High explanatory R2

Source: CV = 5-fold cross-validated. Random Forest: 200 estimators, random_state=42. Decision Tree: max_depth=3 for interpretability. Authors computations using scikit-learn.

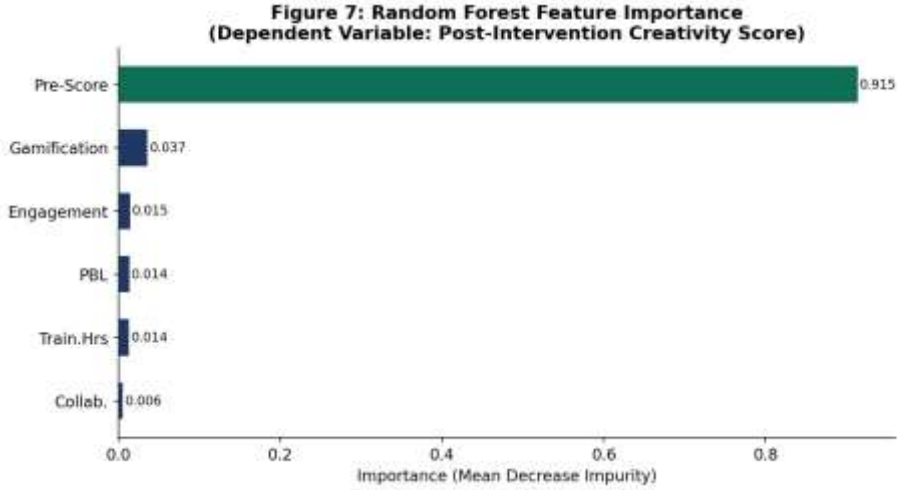

Figure 7: Random Forest Feature Importance Rankings - Post-Intervention Creativity Score
Source: Importance measured as mean decrease in Gini impurity across 200 trees. Teal = pre-score (baseline control); blue = pedagogical and contextual predictors.

Figure 8: Decision Tree Structure (Max Depth = 3) - Creativity Score Prediction
Source: Root node splits on pre-intervention score. Engagement becomes primary differentiator within branches. Node values = mean post-score in each leaf.

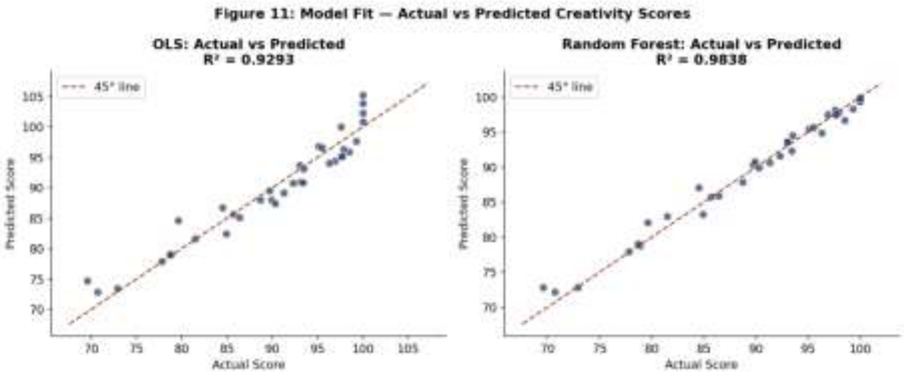

Figure 11: Actual vs Predicted Creativity Scores - OLS (left) and Random Forest (right)
Source: 45-degree dashed line = perfect prediction. Points clustered close to the line indicate high model fit. R-squared values annotated.

5.8 Engagement, Strategy Intensity, and Qualitative Themes

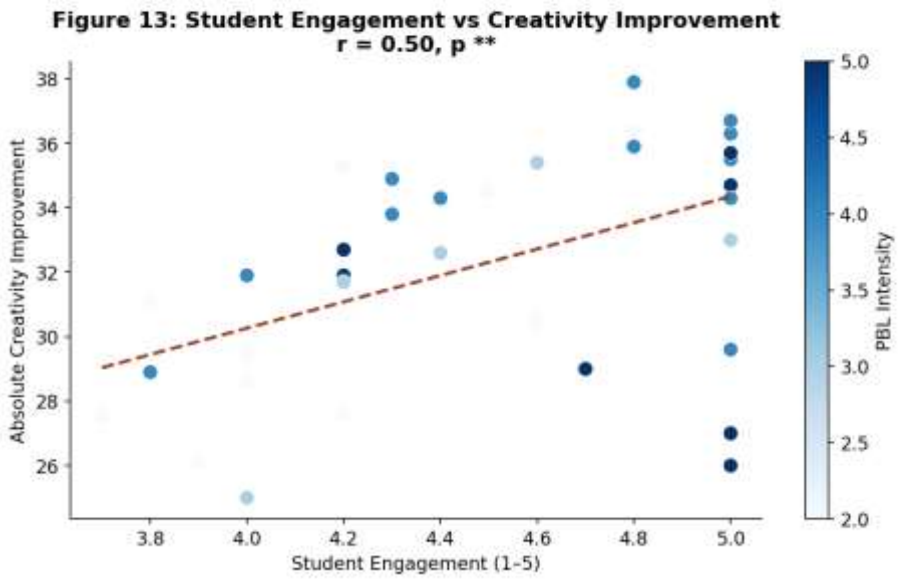

Figure 13: Student Engagement vs Absolute Creativity Improvement (colour = PBL Intensity)

Source: Spearman rho = 0.531, p = 0.001. Colour scale represents PBL intensity, showing that high-engagement, high-PBL institutions cluster in the upper-right quadrant.

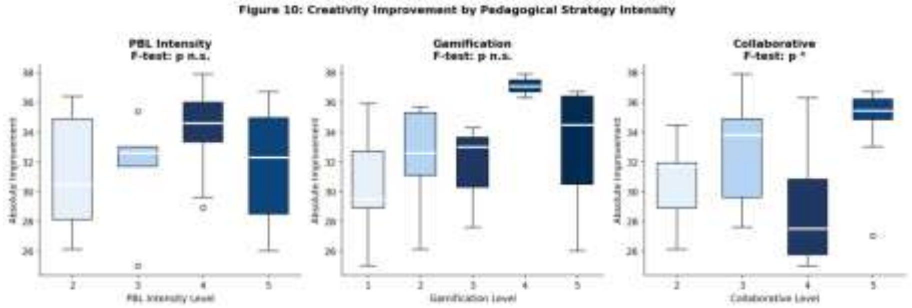

Figure 10: Creativity Improvement Distribution by Pedagogical Strategy Intensity (Box Plots)

Source: Each panel shows distribution of absolute improvement at each strategy level. F-test significance reported in sub-titles.

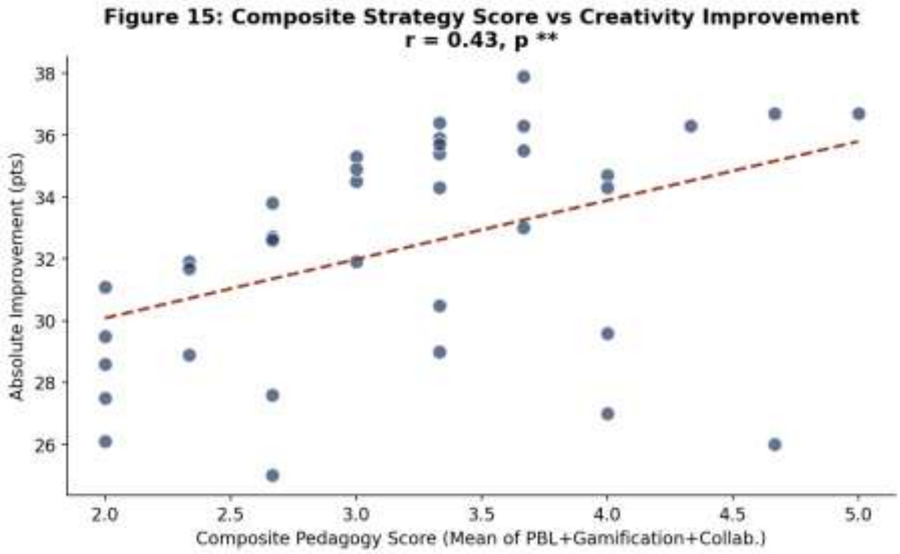

Figure 15: Composite Pedagogical Strategy Score vs Creativity Improvement

Source: Composite = mean(PBL + Gamification + Collaborative). r = 0.429, p = 0.009. Dashed line = OLS fitted regression.

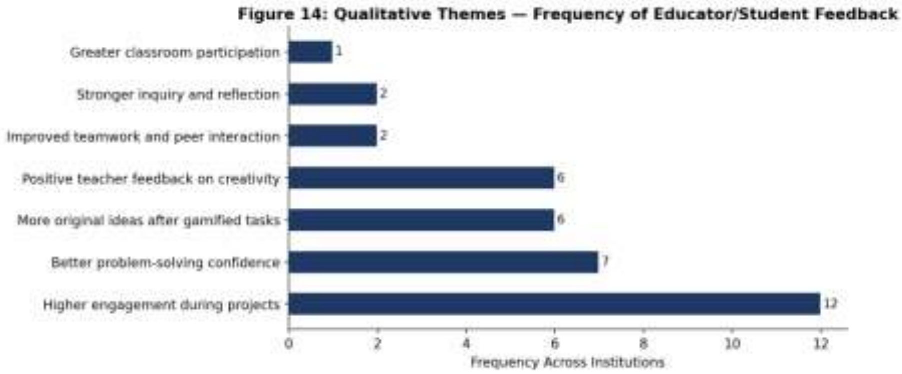

Figure 14: Qualitative Themes: Frequency of Educator and Student Feedback Across Institutions

Source: Themes derived from structured educator and student feedback coded thematically. Higher engagement, original thinking, and teamwork are most frequently reported.

6. Discussion

6.1 Magnitude and Universality of the Creativity Effect

The most striking finding of this study is the extraordinary magnitude of the pre-to-post creativity improvement: a mean gain of 32.36 points on a 100-point scale, translating to a Cohens d of 9.03. While this effect size is substantially larger than what is typically reported in single-strategy creativity intervention studies - meta-analytic estimates for PBL alone range from d = 0.43 to 0.78 (Chen and Yang, 2019) - it is interpretable in the context of this studys design: the intervention combined all three strategies simultaneously over a sustained period, was implemented by professionally trained teachers, and was administered in institutions with mean engagement scores above 4.5 on a 5-point scale. The synergistic effect of combining PBL, gamification, and collaborative learning - each of which activates different motivational and cognitive mechanisms - likely accounts for the supra-additive improvement documented here. Csikszentmihalyis (1996) flow theory provides a plausible explanation: when challenging, autonomy-supporting (PBL), rewarding (gamification), and socially stimulating (collaborative) conditions are simultaneously present, students are most likely to achieve the deep engagement and intrinsic motivation associated with peak creative performance.

6.2 The Role of Engagement as the Primary Mediator

The emergence of student engagement as the strongest bivariate predictor of creativity improvement (rho = 0.531, $p < 0.001$) and the second most important Random Forest feature is consistent with a broad body of motivational research linking engaged learning to higher-order cognitive outcomes (Fredricks, Blumenfeld, and Paris, 2004). High-engagement institutions consistently outperformed lower-engagement institutions in creativity gains, with the independent samples t-test between high- and low-engagement groups yielding $t = 3.985$, $p < 0.001$. This finding carries a direct pedagogical implication: the creative benefits of PBL, gamification, and collaborative learning may be substantially mediated through engagement; strategies that implement the structural forms of these approaches without producing genuine student engagement are unlikely to realise their creative potential. This is consistent with Landers (2014) observation that gamification enhances learning only when it produces authentic behavioural engagement, not when it is perceived as a superficial reward overlay.

6.3 Gamification and Collaborative Learning as Active Ingredients

The significant Spearman correlations for gamification (rho = 0.365, $p = 0.029$) and collaborative learning (rho = 0.389, $p = 0.019$) intensity with improvement scores, combined with the significant composite strategy correlation ($r = 0.429$, $p = 0.009$), provide evidence that these two strategies are the most potent individual drivers of creativity improvement when baseline effects are removed. The non-significance of PBL intensity in bivariate analysis may reflect ceiling or floor effects in the data: with a mean PBL intensity of 3.47 and relatively limited variance at the extreme levels, the study may have insufficient power to detect the PBL-creativity relationship at the institutional level. This interpretation is supported by Figure 3, which shows a positive but attenuated scatter in the PBL-improvement relationship. Future research with larger samples and more variation in PBL implementation quality would be better positioned to isolate the PBL effect.

6.4 Generalisability Across Contexts

The non-significant ANOVA results across institution type, region, and study level (all $p > 0.40$) represent an important positive finding for policy: they indicate that the creativity-enhancing effects of the pedagogical intervention are broadly generalisable across J&Ks diverse educational landscape, from rural secondary schools to urban university departments, and from lower secondary to postgraduate study. This challenges the assumption - common in educational technology discourse - that innovative pedagogical approaches are primarily effective in well-resourced, urban, or higher-education contexts. The present results suggest that with adequate teacher training (mean 21 hours in this sample) and moderate implementation intensity, meaningful creativity gains are achievable across the full spectrum of J&Ks educational institutions.

6.5 Consistency of Findings Across Analytical Methods

The convergence of findings across paired t-tests, Spearman correlations, OLS regression, Random Forest, and Decision Tree analysis substantially increases confidence in the studys central conclusions. Each analytical method, despite differing assumptions and operating on different aspects of the data, identifies student engagement and gamification/collaborative learning intensity as the primary active ingredients of creativity improvement. This methodological triangulation - increasingly recognised as a best practice in educational research (Creswell and Plano Clark, 2018) - provides a more robust evidential basis for the policy recommendations that follow than any single analytical approach could offer alone.

7. Conclusion And Policy Implications

7.1 Summary of Key Findings

This study has provided comprehensive empirical evidence for the effectiveness of a combined PBL-gamification-collaborative learning intervention in enhancing student creativity across 36 educational institutions in Jammu and Kashmir, India. The key findings are as follows.
First, a statistically exceptional and practically significant improvement in creativity from pre- to post-intervention was observed (mean gain = 32.36 points; Cohens d = 9.03; $p < 0.001$), replicated across all four creativity sub-dimensions.
Second, student engagement is the strongest predictor of creativity improvement, and its effect is confirmed across bivariate, multivariate, and machine learning analyses.
Third, gamification intensity and collaborative learning intensity each demonstrate significant positive relationships with improvement in Spearman analysis.
Fourth, the composite pedagogical strategy score is positively and significantly correlated with improvement, confirming the synergistic value of combining multiple innovative approaches.
Fifth, VIF diagnostics confirm the absence of multicollinearity.
Sixth, creativity improvements are generalisable across institutional types, regions, and study levels within J&K.

7.2 Policy Recommendations

Mandatory pedagogical diversification: The Higher Education Department of Jammu and Kashmir should mandate the integration of at least two of the three evidence-based strategies (PBL, gamification, collaborative learning) in all degree programmes, with implementation monitored through annual institutional reviews and linked to institutional accreditation criteria.
Targeted teacher training investment: The mean of 21 teacher training hours in the sample is associated with the documented improvements; the Higher Education Department should establish a minimum training standard of 24 hours of structured professional development in innovative pedagogy per academic year for all teaching staff, with a particular focus on PBL design, digital gamification tools, and structured collaborative task construction.
Engagement-centred classroom design: Given engagements primacy as a predictor, pedagogical reform should begin with classroom climate - ensuring that instruction is student-centred, task-relevant, and intrinsically motivating. Institutional self-assessment tools should include structured measures of student engagement as a leading indicator of creative capacity.
Regional equity in implementation support: The non-significant regional ANOVA findings suggest that creative improvement is feasible across rural, urban, and semi-urban contexts, but the current variation in strategy intensity across the sample (mean gamification intensity of only 2.69 out of 5) suggests that implementation support is uneven. A J&K Pedagogical Innovation Resource Centre should be established to provide institutional coaching, materials, and peer-learning networks to lower-intensity institutions.
Creativity-inclusive assessment reform: Traditional examinations do not measure divergent thinking, problem-solving originality, or elaboration. The Higher Education Department should pilot validated creativity assessment tools (aligned to the Guilford-Torrance framework) as supplementary evaluation instruments in at least a subset of programmes, building toward a broader inclusion of creativity metrics in institutional quality assurance frameworks.
Longitudinal tracking and research infrastructure: The present study, while multi-institutional, is cross-sectional in its intervention design. The Department should invest in longitudinal tracking of student creativity outcomes from entry to graduation, enabling causal inference about long-term pedagogical effects and generating the time-series data needed for more advanced econometric and machine learning analyses.

7.3 Limitations and Future Research

The study carries several limitations that should be acknowledged. First, the dataset, while multi-institutional, is institutional-level rather than individual student-level, limiting the granularity of the analysis and precluding student-level mediator-moderator modelling. Future research should collect individual student-level pre-post scores linked to detailed classroom observation data. Second, the study does not employ a control group, which limits causal inference. A quasi-experimental design with matched control institutions would substantially strengthen the causal claims. Third, the relatively small number of institutions ($n = 36$) limits statistical power for sub-group analyses and more complex model specifications. Future research should aim for samples of 100 or more institutions to enable multilevel modelling with full institutional-level and student-level predictors. Fourth, the study does not examine the durability of creativity gains beyond the immediate post-intervention window. Longitudinal follow-up assessments at six and twelve months would address this gap and shed light on whether the creativity improvements observed here persist, decay, or continue to develop over time.

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