

Effects of Project-based Flipped Learning and Learning Motivation on Collaborative and Creative Thinking Skills in Mathematics: A Multivariate Analysis

Pascalian Hadi Pradana ^{*}, I Wayan Santyasa , I Made Tegeh, and I Komang Sudarma 

Department of Educational Technology, Graduate School, Universitas Pendidikan Ganesha, Bali, Indonesia
Email: pascalian10@gmail.com (P.H.P.); santyasa@undiksha.ac.id (I.W.S.); im-tegeh@undiksha.ac.id (I.M.T.);
ik-sudarma@undiksha.ac.id (I.K.S.)

^{*}Corresponding author

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Abstract—Skill-based mathematics education requires the development of higher-order competencies, particularly collaborative and creative thinking skills. However, prior studies have largely examined instructional models and learning motivation separately, with limited empirical evidence investigating their combined and interactive effects on students' collaborative and creative thinking skills. Therefore, this study aims to examine the effects of Project-Based Flipped Learning (PjBFL) and learning motivation on the collaborative and creative thinking skills of students, as well as the moderating role of learning motivation. A quasi-experimental pretest–posttest nonequivalent control group design was conducted involving 314 grade XI vocational high school students. The experimental group received PjBFL, which combines pre-class digital learning with in-class collaborative projects and flipped learning through structured problem solving, whereas the control group received Direct Instruction. The results showed that PjBFL significantly improved students' collaborative and creative thinking skills compared with Direct Instruction. Learning motivation also had a positive effect, with highly motivated students demonstrating superior collaborative and creative thinking skills. Furthermore, learning motivation interacted with the instructional model, with a significant effect observed on collaborative skills but not on creative thinking skills, suggesting that the instructional model's influence on creative thinking is independent of students' motivation levels. Overall, the interaction effect was more pronounced for collaborative thinking skills than for creative thinking skills. These findings highlight the differential role of learning motivation in shaping higher-order thinking skills, with collaborative thinking having a stronger moderating effect than creative thinking. This study demonstrates the combined and interactive effects of instructional models and motivation in learning mathematics.

Keywords—Project-based Flipped Learning (PjBFL), learning motivation, collaborative skills, creative thinking skills, mathematics education

I. INTRODUCTION

The rapid transformation of 21st-century education requires innovative learning that integrates technology and promotes higher-order thinking skills, particularly collaborative and creative thinking [1–4]. However, despite the curriculum's emphasis on technology-supported, student-centered teaching, teachers continue to dominate mathematics learning, limiting students' opportunities to develop meaningful creative and collaborative thinking [5, 6]. These findings align with those of prior studies indicating that students' creative mathematical thinking skills, particularly fluency and flexibility, remain low. This

limitation is associated with the dominance of conventional instruction and insufficient integration of technological pedagogical content knowledge [7]. Similarly, students' collaborative skills have not developed optimally due to limited opportunities to practice cooperation and a strong individual orientation, while traditional pedagogical approaches inhibit interaction and dialog in mathematics learning [8, 9]. In addition to instructional factors, students' internal factors, such as learning motivation, play a critical role in shaping these skills.

The learning process's success is strongly influenced by students' motivation. Low intrinsic motivation, fear of failure, and limited exposure to motivating instructional strategies significantly reduce student participation and learning outcomes [10]. An unsupportive learning environment can reduce students' motivation and engagement in mathematics learning [11]. Although many studies acknowledge the importance of motivation, it is rarely examined as a moderating variable in investigating the effectiveness of innovative instructional models in developing 21st-century skills.

These issues are further reflected in classroom practices. Observations conducted in vocational secondary schools indicate that mathematics instruction remains predominantly lecture-based, resulting in limited student interaction and low performance in collaborative problem-solving and creative mathematical reasoning tasks. Students tend to rely on teacher explanations and procedural exercises, with few opportunities to engage in discussion, idea exchange, or open-ended problem solving. The limited use of varied instructional models and digital learning media further intensifies these conditions, reducing students' active participation and motivation for learning. These findings are consistent with previous studies reporting that conventional mathematics instruction, minimal integration of creative problem-solving strategies, and limited use of educational technology hinder the development of collaborative and creative thinking skills required in 21st-century learning [12, 13]. This issue is particularly critical in vocational education, where students are expected to develop problem-solving, teamwork, and innovative thinking skills that are directly relevant to future workplace demands. However, the implementation of innovative instructional approaches is often constrained by inadequate technological infrastructure, limited internet connectivity, and insufficient teacher preparation in integrating digital technologies into

classroom practice.

Without appropriate instructional strategies, these conditions may further hinder the development of students' collaborative and creative thinking skills, thus requiring an instructional model that can effectively develop both skills [14]. To address these challenges, an instructional approach that actively engages students in meaningful and collaborative learning processes is required. PjBL is a relevant approach that serves as the foundational framework for PjBFL, a learning model that uses contextual problems to construct and integrate new knowledge through real projects [15]. Various studies have shown that PjBL improves 21st-century skills, including collaboration, creative thinking, problem solving, motivation, and academic achievement in mathematics [16–18]. This effectiveness is attributed to students' active engagement in authentic problem-solving tasks, collaborative interactions, and knowledge construction through meaningful project experiences. In addition, the collaborative environment in PjBL fosters the exchange of ideas and supports the development of innovative thinking [19] while, also enhancing student engagement and participation [20].

However, PjBL implementation is often time-intensive because of its comprehensive stages, including planning, implementation, and assessment [21]. The complexity of project activities, such as in-depth investigation, collaboration, and iterative revision, further contributes to the longer instructional time compared with that of conventional methods [22]. In addition, time constraints have been identified as a major challenge in the effective implementation of PjBL [23]. To overcome these limitations, PjBL can be integrated with the Flipped Learning (FL) approach to improve instructional efficiency while maintaining the collaborative and inquiry-based characteristics of project-based learning. Project-Based Flipped Learning (PjBFL), which integrates Project-Based Learning (PjBL) and Flipped Learning (FL), combines technology-based independent learning outside the classroom with collaborative problem-solving activities during classroom instruction [24]. The flipped classroom approach allows students to independently learn material through digital media before face-to-face meetings, allowing them to focus on discussion, concept clarification, and collaborative project completion [25, 26]. Several studies have demonstrated the educational potential of PjBFL in supporting active and technology-enhanced mathematics learning [27–30].

Despite the growing body of research on technology-enhanced mathematics learning, several gaps remain. Previous studies have predominantly examined PjBL or FL as separate instructional approaches with, limited attention to their integrated application. Prior research has generally focused on single learning outcomes, such as collaborative skills or creative thinking, rather than simultaneously examining both within a multivariate framework. In addition, the role of learning motivation as a moderating variable in influencing the effectiveness of instructional models has not been sufficiently explored.

To address these gaps, this study investigates Project-Based Flipped Learning (PjBFL), an instructional model Integrating Project-Based Learning (PjBL) and

Flipped Learning (FL), and compares its effectiveness with Direct Instruction. This study aims to examine the effects of the instructional model and learning motivation on the collaborative and creative thinking skills of students and the interaction between these variables. In this study, PjBL serves as the theoretical foundation of the instructional design, whereas PjBFL represents the integrated instructional model implemented in the experimental group. Direct Instruction was used as the comparison model. Based on these considerations, the research problem is formulated as follows: How does PjBFL affect students' collaborative and creative thinking skills in mathematics? How is this relationship influenced by students' learning motivation?

To address this problem, the following hypotheses are proposed:

H1: Significant multivariate differences in collaborative skills and creative thinking between students taught using the PjBFL model and those taught using Direct Instruction.

H2: Significant multivariate differences in collaborative skills and creative thinking between students with high and low motivation for learning.

H3: A significant multivariate interaction effect was observed between the instructional model (PjBFL vs. Direct Instruction) and learning motivation on collaborative skills and creative thinking.

H4: A significant interaction effect exists between the instructional model and learning motivation on students' creative thinking skills.

H5: A significant interaction effect exists between the instructional model and learning motivation on collaborative skills of students.

II. LITERATURE REVIEW

PjBL is a student-centered instructional approach that engages learners in collaborative project activities to construct knowledge and solve authentic problems [31, 32]. Through meaningful project engagement, PjBL facilitates collaborative interaction and creative problem-solving while promoting active participation in learning [33, 34]. However, its implementation often involves challenges related to time management, unequal participation, and classroom organization.

To address these limitations, Flipped Learning (FL) has been integrated with PjBL to form Project-Based Flipped Learning (PjBFL), an instructional model integrating independent pre-class learning with collaborative in-class project activities [35, 36]. This integration enables classroom time to be used more efficiently for discussion, problem solving, and collaborative knowledge construction.

Previous studies suggest that the integration of project-based learning and flipped learning through the PjBFL model creates a learning environment that promotes active participation, collaborative interaction, and reflective problem solving. These instructional characteristics contribute to the development of collaborative skills and creative thinking while simultaneously enhancing students' learning motivation [37–39].

Learning motivation also plays an important role in determining students' engagement and learning performance. Students with higher motivation tend to participate more actively in collaborative activities, demonstrate greater

persistence in problem solving, and exhibit stronger performance in creative thinking [40–44]. Therefore, students with higher learning motivation may benefit more from PjBFL environments because the model relies heavily on active participation, self-directed learning, and sustained collaborative engagement.

Although previous studies consistently report positive effects of PjBFL on communication, collaboration, and creative thinking, most investigations remain limited to single outcome variables and rarely examine learning motivation as a moderating variable [45]. Furthermore, limited research has simultaneously examined collaborative skills and creative thinking within a unified multivariate framework. Few studies have specifically investigated how learning motivation moderates the relationship between instructional models and the development of collaborative and creative thinking skills, particularly in vocational mathematics education. Structured PjBFL-based instructional tools have also been shown to support more effective classroom implementation [46, 47], indicating that well-designed PjBFL environments can facilitate the development of higher-order competencies.

Therefore, this study provides a comparative analysis of PjBFL and Direct Instruction in mathematics learning, focusing on their effects on students' collaborative skills and creative thinking. This study offers new empirical insights into the interaction between instructional design and learner characteristics in shaping higher-order competencies by incorporating learning motivation as a moderating variable and applying a multivariate analytical approach.

III. MATERIALS AND METHODS

A. Design and Approach

This study employed a quasi-experimental design with a non-equivalent control group structure. Random assignment of participants was not feasible due to institutional constraints; therefore, intact classes were used as the unit of analysis. Nine classes, consisting of experimental and control groups, participated in the study. The experimental group was taught using PjBFL, whereas the control group received Direct Instruction. A pretest was administered before the intervention to ensure baseline comparability. The research procedure consisted of three stages: pretest, treatment, and posttest. During the pretest phase, the students completed assessments to measure their initial collaborative and creative thinking abilities and completed a learning motivation questionnaire. Students were categorized into high and low motivation groups based on the motivation scores based on the median score.

The instructional models (PjBFL vs. Direct Instruction) served as the independent variable, learning motivation functioned as a moderating variable, and collaborative and creative thinking skills were treated as dependent variables. Pretest scores were included as covariates to control for the differences between the groups. This design allows the examination of both the main and interaction effects using MANCOVA.

The intervention included five instructional sessions that were implemented over approximately eight weeks, with some sessions extending beyond one week due to the

complexity of project-based activities. Each session lasted 120 min and followed three structured phases: (1) pre-class learning, in which students independently accessed digital instructional materials such as videos and online modules; (2) in-class collaborative project work, in which students worked in groups to solve contextual mathematical problems and develop project outputs; and (3) presentation and reflective discussion, in which students presented their project outcomes and engaged in peer feedback and evaluation. Table 1 summarizes these phases to provide a structured comparison between the experimental and control groups.

Table 1. Comparison of instructional procedures

Phase	PjBFL (experimental)	Direct instruction (control)
Pre-class	Independent digital learning	No pre-class activity.
In-class	Collaborative project work	Teacher-centered explanation
Post-class reflection/	Presentation and peer feedback	Review of the exercises
Activity	Problem solving and discussion	Procedural exercises
Output	Project-based products	Individual tasks
Interaction	High student interaction	Limited interaction

The instructional intervention was implemented in vocational mathematics classes covering circle concepts, including circle equations, the position of lines relative to circles, arc length, and sector area. In the PjBFL group, students completed collaborative projects in the form of interactive posters and infographics using GeoGebra to analyze contextual problems related to circles and line positions. Flipped learning activities were conducted through pre-class instructional videos, digital handouts, and e-modules distributed via Google Classroom. Before classroom sessions, students independently studied the assigned learning materials and completed preliminary learning tasks. During in-class sessions, students engaged in collaborative discussions, project development, contextual problem-solving activities, and group presentations facilitated by the teacher. Post-class activities included project revision, reflective learning tasks, and submission of final project outputs through the digital learning platform.

B. Population and Sample

The research sample was drawn from Grade XI students at two vocational high schools, SMKN 2 and SMKN 4 in Jember Regency, East Java, comprising 174 students from SMKN 2 and 140 students from SMKN 4. Purposive sampling was used to select nine intact classes based on specific criteria, including comparable academic ability, similar curriculum exposure, and the availability of teachers willing to implement the instructional intervention. This approach ensured that the selected classes were suitable for comparison within the quasi-experimental design. This sampling and grouping approach is consistent with quasi-experimental research practices in educational settings, where ecological validity by maintaining intact classes.

Five classes were selected from SMKN 2 and four from SMKN 4. Three classes from SMKN 2 and two from SMKN 4 were assigned to the experimental group, and the remaining classes were assigned to the control group. A larger number of classes were allocated to the experimental group to ensure sufficient exposure to the PjBFL intervention and to increase

the stability and generalizability of the treatment effects. This allocation also helped maintain statistical power in detecting multivariate effects in a real classroom setting. Due to administrative and scheduling constraints and the need to maintain intact classroom structures, students could not be randomly reassigned. Therefore, class assignment into experimental and control groups was conducted at the class level without altering the composition of the students. A Total of 314 students participated in the study, including 170 students in the experimental group receiving PjBFL and 144 students in the control group receiving Direct Instruction.

C. Data Collection Techniques and Instruments Used

Data were collected through observations, tests, rubrics, and questionnaires to measure collaborative and creative thinking skills and learning motivation. Three main instruments were employed to measure the research variables. First, collaborative skills were assessed using structured observation sheets supported by analytic rubrics covering participation, communication, teamwork, responsibility, and conflict resolution. To ensure scoring consistency, observers were trained using standardized guidelines and scoring rubrics before data collection. In addition, scoring procedures were discussed among observers to minimize subjectivity during the assessment process. Each indicator was rated using a four-point scale ranging from 1 (very low) to 4 (very high). Scores were averaged across indicators to produce a composite collaborative skill score for each student. During classroom activities, observations were conducted by trained observers, and scoring consistency was ensured using standardized guidelines. Second, creative thinking skills were measured using a four-item open-ended essay test designed to assess four creative thinking dimensions: fluency, flexibility, elaboration, and originality. Each item was scored using a rubric ranging from 0 to 4 for each dimension, resulting in a maximum total score of 16. The students' responses were evaluated using a rubric-based scoring system, with each dimension scored on a predefined scale to ensure objectivity and consistency. Third, learning motivation was measured using a 40-item Likert-scale questionnaire assessing interest, effort, persistence, self-efficacy, and goal orientation. Responses were rated on a five-point scale ranging from strongly disagree to strongly agree. The total motivation score ranged from 40 to 160, with higher scores indicating stronger motivation to learn. The composite scores for each variable were calculated by aggregating the indicator scores, with higher scores indicating higher levels of the respective constructs.

D. Instrument Validity and Reliability

A pilot study involving 32 Grade XI students who had previously learned the circle topic was conducted to evaluate the instruments' validity and reliability. Content validity was established through expert judgment by three specialists in Educational Technology and Mathematics Education, who evaluated the instruments based on relevance, clarity, and alignment with learning objectives. Construct validity was examined using corrected item-total correlations. The results indicated that the creative thinking test, collaborative skills rubric, learning motivation questionnaire, and PjBFL instructional module were appropriate for use with minor revisions, particularly in improving item clarity, increasing

the use of open-ended tasks, and strengthening indicators of flexibility and collaborative interaction.

Table 2. Item-total statistics

Question	Scale mean if the item is deleted	Scale Variance if the item is deleted	Corrected Item-Total Correlation	Cronbach's alpha value if the item is deleted
1	27.38	33.919	0.824	0.954
2	27.31	34.544	0.788	0.956
3	27.34	34.943	0.768	0.956
4	27.34	34.814	0.783	0.956
5	27.22	34.822	0.878	0.952
6	27.03	35.064	0.893	0.951
7	27.06	35.157	0.838	0.953
8	27.28	35.305	0.817	0.954
9	27.09	35.378	0.829	0.954
10	27.19	36.222	0.790	0.955

Table 2 presents the analysis results. Construct validity was examined using corrected item-total correlations. All items met the validity criteria, with correlation coefficients ranging from 0.768 to 0.893, exceeding the minimum acceptable threshold ($r > 0.30$). These findings indicate that all items were valid and adequately represented the intended construct. In addition, the scale's stability was confirmed, as the scale mean and variance remained relatively consistent if an item was deleted, indicating that no single item disproportionately influenced the overall score. Therefore, all items were retained without revision.

Table 3. Reliability statistics

Instrument	Number of Items	Cronbach's Alpha	Interpretation
Creative Thinking Test	10	0.959	Excellent reliability

Table 3 presents the analysis results. The reliability analysis demonstrated a Cronbach's alpha coefficient of 0.959, indicating excellent internal consistency. Furthermore, Cronbach's alpha values ranged from 0.951 to 0.956, indicating that the removal of any item would not significantly improve the reliability of the instrument. These results confirm the high reliability and suitability of the proposed instrument for data collection.

Expert validation confirmed that the collaborative skills rubric and learning motivation questionnaire captured the intended constructs. The collaborative rubric included indicators such as communication, teamwork, responsibility, conflict resolution, and empathy, while the motivation questionnaire covered interest, effort, persistence, self-efficacy, and goal orientation. All instruments were deemed appropriate for measuring collaborative skills and learning motivation in the context of mathematics learning.

E. Data Analysis

Factorial Multivariate Analysis of Covariance (MANCOVA) was used to examine the effects of the instructional models (PjBFL vs. Direct Instruction) and learning motivation (high vs. low) on the collaborative and creative thinking skills of students. The test scores for both dependent variables were included as covariates to control differences in the initial groups. MANCOVA was chosen because it enables the simultaneous analysis of multiple dependent variables while controlling for covariates, thereby reducing Type I error and providing a more comprehensive

understanding of the relationships among variables. This method was selected because the study involved multiple dependent variables, such as students' collaborative skills and creative thinking, and aimed to examine both main and interaction effects while controlling for pretest scores as covariates. The instructional models (Project-Based Flipped Learning vs. Direct Instruction) was treated as the independent variable, learning motivation as a moderating variable, and pretest scores as covariates. Before hypothesis testing, several statistical assumptions were examined to ensure the validity of the analysis. These included the following: 1) normality, 2) linearity of the relationship between covariates and dependent variables, 3) absence of multicollinearity, 4) homogeneity of variance (Levene's test), 5) equality of variance-covariance matrices (Box's M test), and 6) homogeneity of regression slopes. The Shapiro–Wilk test was used to assess normality, and the Mahalanobis distance was used to examine multivariate outliers. Linearity, variance homogeneity, and regression slope homogeneity were tested using standard procedures, and the equality of covariance matrices was assessed using Box's M test. All assumptions were met, and where minor violations occurred, Pillai's Trace was used because of its robustness.

In the context of multivariate analysis, several simulation studies have shown that multivariate test statistics, such as MANCOVA, maintain their robustness to violations of normality assumptions when the sample size is adequate, so that they can still provide reliable results even if the data are not completely normal [48]. Hypothesis testing was conducted using MANCOVA, followed by multivariate and univariate analyses (Tests of Between-Subject Effects). Statistical significance was set at $\alpha = 0.05$, and effect sizes were reported using partial eta squared (η^2), with values of 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively. All statistical analyses were conducted using IBM SPSS Statistics version 27.

IV. RESULT AND DISCUSSION

A. Result

Baseline equivalence between the experimental and control groups was established using the pretest scores. The results indicate no significant differences in creative thinking and collaborative skills between the groups, confirming that both groups were comparable before the intervention (Table 4). Therefore, any differences observed in the posttest can be attributed to the instructional treatment.

Table 4. Baseline equivalence

Variable	t	df	p-value	Mean Difference	95% CI
Pretest for Creative Thinking	1.426	312	0.155	-0.240	[-0.571, 0.091]
Pretest Collaborative	1.319	312	0.188	0.471	[-0.231, 1.173]

As presented in Table 4, no statistically significant differences in creative thinking ($t = 1.426$, $df = 312$, $p = 0.155$) or collaborative skills ($t = 1.319$, $df = 312$, $p = 0.188$) were found between the two groups. The 95% confidence intervals for both variables included zero, further supporting the absence of significant differences. Effect size analysis using

Cohen's d indicated trivial differences between groups ($d < 0.20$), indicating trivial effect sizes and supporting the baseline equivalence between groups. These findings demonstrate that the experimental and control groups were comparable at baseline. Therefore, any differences observed in the posttest outcomes can be more confidently attributed to the instructional intervention than to pre-existing group differences.

1) Normality test

The normality assumption in MANCOVA refers to the multivariate distribution of residuals. The Shapiro–Wilk test was used to assess univariate normality on the residuals of each dependent variable (Table 5).

Table 5. Normality tests (residuals)

Variable	Shapiro–Wilk Statistic	p-value	Interpretation
Creative Thinking	0.975	<0.001	Not normal
Collaborative Skills	0.991	0.061	Normal

As shown in Table 5, the residuals for creative thinking were not normally distributed ($p < 0.05$), whereas those for collaborative skills met the normality assumption ($p > 0.05$). This finding is a partial violation of univariate normality. The creative thinking residuals were non-normal. Although the Shapiro–Wilk test indicated non-normal residuals for creative thinking ($p < 0.05$), MANCOVA was retained because multivariate analyses are generally robust to moderate violations of normality, particularly with large and balanced samples [49, 50]. The Mahalanobis distance was used to detect multivariate outliers to further evaluate multivariate normality (Table 6). The robustness of the MANCOVA procedure addressed the minor deviation from univariate normality, allowing the analysis to proceed without compromising the findings' validity.

Table 6. Mahalanobis distance

Statistic	Value
Sample size (N)	314
Maximum Mahalanobis distance	12.38
Chi-square critical value ($df = 4$, $\alpha = 0.001$)	18.47
Multivariate outliers were detected	None

Table 6 shows that multivariate normality was further evaluated using the Mahalanobis distance to detect outliers. The maximum distance was 12.38, which was below the critical chi-square value ($\chi^2 = 18.47$, $df = 4$, $p < 0.001$). Furthermore, all associated Mahalanobis probability values ($p\text{-Mah}_i$) were ≥ 0.001 , indicating no multivariate outliers. These findings indicate that multivariate normality was satisfied. Minor univariate deviations did not compromise the MANCOVA results' robustness. The results support the multivariate normality assumption.

2) Relationship between the covariates and the dependent variables

The linearity assumption was tested to ensure that covariates function appropriately as control variables in the MANCOVA model. This assumption requires a linear relationship between covariates and dependent variables to allow accurate statistical adjustment. Table 7 presents the linearity test results.

As presented in Table 7, the results indicate mixed evidence regarding the linearity assumption. The

relationships involving pretest collaborative skills met the linearity assumption, as indicated by non-significant deviation from linearity ($p > 0.05$). The relationships involving pretest creative thinking showed a significant deviation from linearity ($p < 0.05$), indicating that the relationships were not strictly linear. Although a significant deviation from linearity was observed ($p < 0.05$), such violations should be interpreted with caution because, they may arise from measurement variability and do not necessarily invalidate the model [51]. Furthermore, parametric models, such as MANCOVA, remain robust and yield consistent estimates even under certain model misspecifications [52].

Table 7. Linearity

Covariate * Dependent variable	Linearity (Sig.)	Deviation from linearity (Sig.)	Interpretation
Pretest Collaborative * Creative Thinking	0.423	0.935	Linear
Pretest Collaborative * Collaborative Skills	0.001	0.180	Linear
Pretest of Creative Thinking * Creative Thinking	0.000	0.000	Non-linear
Pretest for Creative Thinking and * Collaborative Skills	0.013	0.003	Non-linear

Note: * indicates an interaction term

Although the linearity assumption was partially violated, the analysis was retained for several methodological reasons. First, MANCOVA is considered relatively robust to moderate linearity violations, particularly in studies with adequate sample sizes. Second, the inclusion of covariates was theoretically justified because pretest, scores are essential for controlling baseline differences between groups. Third, other key assumptions, such as multivariate normality, homogeneity of variance, and equality of covariance matrices, were satisfied, supporting the overall validity of the model. Therefore, MANCOVA remained acceptable for analysis with, careful interpretation of the results, particularly for effects involving the pretest creative thinking covariate.

3) Absence of multicollinearity

A multicollinearity test was conducted to ensure that the independent variables (instructional model and learning motivation) and covariates (pretest creative thinking and pretest collaborative skills) were not highly correlated, allowing each variable to contribute uniquely to the model (Table 8).

Table 8. Multicollinearity

Variable	Tolerance	VIF
Instructional Model	0.970	1.031
Learning Motivation	0.915	1.093
Pretest for Creative Thinking	0.930	1.075
Pretesting Collaborative Skills	0.983	1.017

All variables exhibited tolerance values greater than 0.10 and variance inflation factor values well below the critical threshold of 10 (Table 8). The tolerance values ranged from 0.915 to 0.983, while the VIF values ranged from 1.017 to 1.093. These results indicate no evidence of multicollinearity among the independent variables and covariates. Therefore, the multicollinearity absence assumption is satisfied, and the variables can be simultaneously included in the MANCOVA

model without compromising the validity of the analysis.

4) Homogeneity of variance

In this study, a homogeneity of the variance test was conducted to determine whether the variances of creative thinking and collaborative skills were equal across the treatment groups. This assumption is essential for parametric statistical analyses, including multivariate analysis of covariance, as unequal variances may compromise the validity of the results. Therefore, Levene's test was employed to assess the homogeneity of variances between groups at a significance level of $\alpha = 0.05$ (Table 9).

Table 9. Homogeneity of the variance tests

Variable	Levene Statistic	df1	df2	p-value	Interpretation
Developing creative thinking skills	0.624	1	312	0.430	Homogeneous
Collaborative Skills	0.076	1	312	0.783	Homogeneous

As shown in Table 9, the results of the homogeneity of variance test using Levene's test showed that the variance in the dependent variables (creative thinking skills and collaborative skills), was homogeneous in both categories of the motivation independent variable. This finding was based on the mean-based Levene significance values of 0.430 and 0.783 for creative thinking skills and collaborative skills. All these significance values are above the threshold of $\alpha = 0.05$; therefore, no significant differences in variance were observed between the groups. Thus, this assumption indicates that the data are suitable for proceeding to the next stage of MANCOVA analysis to simultaneously test the effect of independent variables on dependent variables by controlling for relevant covariates.

5) Equality of variance-covariance matrices

Before conducting MANCOVA, the equality of variance-covariance matrices was tested using Box's M test. This test is essential in multivariate analysis because, it evaluates whether the variance and covariance structures of the dependent variables are equivalent across groups, thereby ensuring the validity of multivariate comparisons (Table 10).

Table 10. Box's M test of the equality of covariance matrices

Statistic	Value
Box's M	11.985
F	1.210
df1	9
df2	1.280.974
p-value	0.285

As presented in Table 10, the test yielded a non-significant result (Box's M = 11.985, $p = 0.285$). The null hypothesis of equal covariance matrices is not rejected because the p-value exceeds the recommended threshold of 0.001. These results indicate that the assumption of homogeneity of variance-covariance matrices is fulfilled, allowing the MANCOVA analysis to proceed with valid multivariate inferences.

6) Homogeneity of regression slopes

The regression slope homogeneity test was conducted to ensure that the relationship between the covariates and the dependent variable was the same (parallel) across all independent variable groups, so that the MANCOVA

covariate adjustment was consistent (Table 11).

As shown in Table 11, most interaction terms between the instructional model and covariates were not statistically significant ($p > 0.05$), indicating that the regression slopes were generally homogeneous across instructional groups. However, several interaction effects involving learning motivation were statistically significant ($p < 0.05$), and the relationship between certain covariates and dependent variables varied across motivation categories.

Table 11. Homogeneity test of the regression slopes

Interaction Term	Dependent Variable	p-value	Interpretation
Instructional Model * Pretest of Creative Thinking	Creative Thinking	0.216	Homogeneous
Instructional Model * Pretest of Creative Thinking	Collaborative Skills	0.735	Homogeneous
Instructional Model * Collaborative Pretest	Creative Thinking	0.872	Homogeneous
Instructional Model * Collaborative Pretest	Collaborative Skills	0.020	Not homogeneous
Motivation * Pretest for Creative Thinking	Creative Thinking	0.004	Not homogeneous
Motivation * Collaborative Pretest	Creative Thinking	0.000	Not homogeneous

Note: * indicates an interaction term

These findings indicate a partial violation of the regression slope homogeneity assumption. Nevertheless, the analysis was retained for several reasons. First, the primary violations were limited to interactions involving motivation, whereas the instructional model's main factor of interest met the assumption. Second, MANCOVA is considered relatively robust to moderate violations of this assumption, particularly in studies with adequate sample sizes. Third, the inclusion of covariates to control for baseline differences remained theoretically justified. Therefore, the MANCOVA analysis was conducted without including interaction terms between covariates and independent variables in the final model. Thus, the assumption of regression slope homogeneity is partially fulfilled. Although significant interactions were found in some pairs of covariates and independent variables, these interactions were only tested as prerequisites and were not included in the main model. Further MANCOVA analysis was conducted without including covariate $\times$ independent variable interactions, with an emphasis on multivariate results and careful interpretation in accordance with the identified assumption limitations. The results were interpreted with caution, considering the identified limitations in this assumption.

B. Hypothesis Testing

Hypothesis testing was conducted using factorial MANCOVA to examine the effects of the instructional models (PjBFL vs. Direct Instruction), learning motivation, and their interaction on students' collaborative skills and creative thinking while controlling for, pretest scores. Detailed statistical results are presented in Tables 12 and 13.

The multivariate results (Table 12) indicate that the instructional model, learning motivation, and their interaction significantly influence students' collaborative skills and creative thinking. Based on partial η^2 values, the

effect of learning motivation was classified as large ($\eta^2 = 0.170$), whereas the instructional model demonstrated a medium effect size ($\eta^2 = 0.094$). The interaction effect between instructional model and motivation showed a small-to-medium effect ($\eta^2 = 0.046$). These findings indicate that both instructional design and internal motivation play an important role in shaping students' collaborative skills and creative thinking.

Table 12. Multivariate test (Mancova – Pillai's trace)

Effect	Pillai's Trace	F	df	p-value	Partial η^2
Pretest for Creative Thinking	0.142	25.310	2.307	< 0.001	0.142
Pretest Collaborative	0.022	3.420	2.307	0.034	0.022
Instructional Model	0.094	15.977	2.307	< 0.001	0.094
Learning Motivation	0.170	31.407	2.307	< 0.001	0.170
Model $\times$ Motivation	0.046	7.429	2.307	0.001	0.046

In addition, the pretest variables contribute meaningfully to the model, indicating that the initial abilities of students remain an important factor in interpreting the results of the post-intervention. This confirms the importance of controlling baseline differences in quasi-experimental research.

Table 13. Univariate MANCOVA

Effect	Creative Thinking (F, p, η^2)	Collaborative Skills (F, p, η^2) respectively
Pretest of Creative Thinking Skills	50.759, <0.001, 0.141	8.170, 0.005, and 0.026
Pretest of the collaborative skills	0.027, 0.869, <0.001	6.155, 0.014, and 0.020
Instructional Model	30.787, <0.001, 0.091	9.931, 0.002, and 0.031
Learning Motivation	20.670, <0.001, 0.063	60.017, <0.001, and 0.163
Model * Motivation	3.521, 0.062, 0.011	5.799, 0.017, and 0.018

Note: * indicates an interaction term

Univariate analyses were conducted to further examine the effects of each dependent variable (Table 13). The results show that both the instructional model and learning motivation significantly affect students' creative thinking and collaborative skills. However, the interaction effect differs between the two skill domains.

The interaction between the instructional model and learning motivation is significant for collaborative skills but not for creative thinking. This indicates that collaborative skills are more sensitive to the combined influence of instructional strategy and motivation level, whereas each factor more independently influences creative thinking.

The results of the MANCOVA analysis (Tables 12 and 13) provide clear evidence supporting the proposed hypotheses. First, the instructional model significantly influenced students' collaborative skills and creative thinking, indicating that students who were taught using PjBFL demonstrated different performance compared with those who received Direct Instruction. Therefore, H1 is supported.

Second, learning motivation has a significant effect on collaborative skills and creative thinking, with students

possessing higher motivation demonstrating stronger performance in both skill domains. Thus, H2 is supported.

Third, the multivariate analysis revealed a significant interaction between the instructional model and learning motivation, indicating that the effectiveness of PjBFL compared to Direct Instruction depends on the motivation levels of students when both skills are considered simultaneously. Accordingly, H3 is supported.

The interaction effect was not significant for creative thinking at the univariate level. The instructional model's influence on creative thinking operates relatively independently of students' motivation levels. Therefore, H4 is not supported.

In contrast, the interaction effect is significant for collaborative skills, indicating that the impact of the instructional model varies across different levels of learning motivation. This finding highlights that collaborative skills are particularly sensitive to the combined influence of instructional strategy and student motivation. Hence, H5 is supported.

Overall, these findings indicate that both the instructional model and learning motivation play significant roles in shaping collaborative skills and creative thinking. However, their interaction is more critical in influencing collaborative skills than creative thinking, and the development of collaborative skills requires a stronger alignment between the pedagogical approach and students' motivational characteristics.

C. Discussion

1) Simultaneous differences in collaborative skills and creative thinking using direct instruction and the PjBFL model

The first hypothesis examined whether there was a simultaneous difference in collaborative and creative thinking skills between students using the PjBFL model and those receiving Direct Instruction. The findings indicate that PjBFL was more effective than Direct Instruction in improving students' collaborative and creative thinking skills. This effectiveness may be attributed to the instructional structure of PjBFL, which integrates independent pre-class preparation with collaborative project-based classroom activities. Such a learning environment promotes active engagement, peer interaction, collaborative problem solving, and deeper cognitive processing, all of which support the development of collaborative and creative thinking skills [53, 54]. In contrast, Direct Instruction primarily emphasizes teacher-centered explanation and procedural learning, providing fewer opportunities for interaction and reflective problem solving. However, the effect size observed in this study was more moderate than that reported in some previous studies. One possible explanation is the relatively short intervention period and the vocational school context, where students may require longer adaptation to student-centered learning environments. Future research should consider longer implementation periods and more diverse samples to better examine the sustainability of these effects.

Fig. 1 illustrates higher creative thinking scores among students taught using PjBFL suggest that collaborative project activities and independent pre-class preparation

encourage students to explore multiple solution strategies and engage more actively in mathematical reasoning processes. This pattern supports the effectiveness of PjBFL in facilitating idea generation, problem exploration, and higher-order thinking processes through collaborative and project-oriented learning activities.

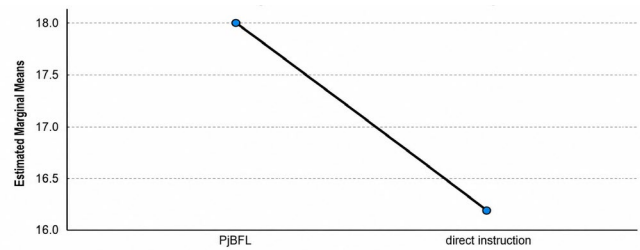


Fig. 1. Estimated marginal means of Creative Thinking Skills among students learning mathematics through the PjBFL and direct instruction models.

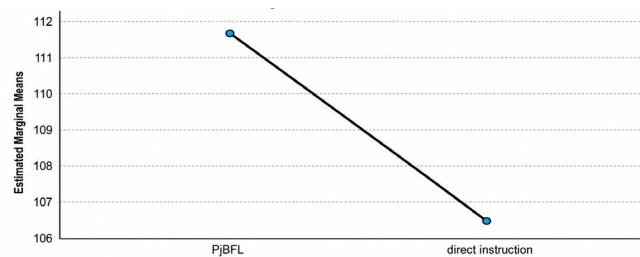


Fig. 2. Estimated marginal means of Collaborative Skills among students learning mathematics through the PjBFL and direct instruction models.

Fig. 2 indicates that students in the PjBFL group demonstrated higher collaborative skill scores than those in the Direct Instruction group. The interactive and project-oriented nature of PjBFL appears to encourage greater participation, communication, and teamwork during mathematics learning activities.

2) Simultaneous differences in collaborative skills and creative thinking between students with high and low learning motivation

The second hypothesis examined whether students with high versus low mathematics learning motivation differed simultaneously in collaborative and creative thinking skills. Students with higher learning motivation demonstrated stronger collaborative and creative thinking performance than those with lower motivation. This finding may be explained through self-determination theory, which suggests that highly motivated students are more likely to participate actively in discussions, persist in challenging tasks, and contribute meaningfully to collaborative learning activities. Learning motivation plays a critical role in shaping students' engagement and participation, which in turn influences the development of collaborative and creative thinking skills. Consistent with prior studies emphasizing the role of motivation in cognitive and social engagement, effect magnitudes may vary due to sample characteristics or context. However, the strength of this relationship may vary depending on contextual factors such as the classroom environment and instructional design. These findings indicate that enhancing students' motivation should be a key consideration when implementing instructional models aimed at improving collaborative and creative thinking skills.

Fig. 3 presents the estimated marginal means of creative thinking skills based on students' levels of learning

motivation after controlling for pretest differences. Students with high learning motivation achieved higher adjusted mean scores in creative thinking skills than those with low learning motivation. This finding suggests that learning motivation plays an important role in enhancing students' ability to generate ideas, explore alternative solutions, and engage in higher-order thinking processes.

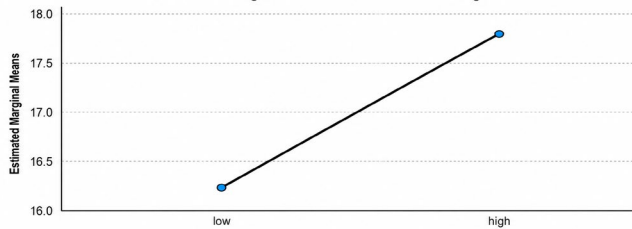


Fig. 3. Estimated marginal means of creative thinking skills between students with high and low learning motivation.

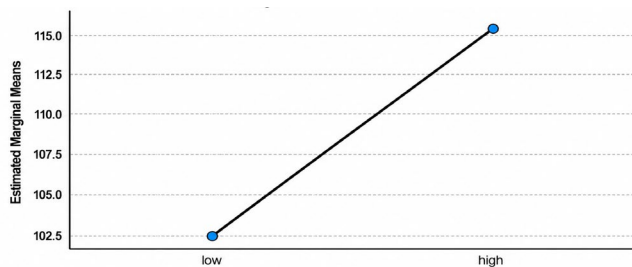


Fig. 4. Estimated marginal means of collaborative skills between students with high and low learning motivation.

Fig. 4 illustrates the estimated marginal means of collaborative skills among students with different levels of learning motivation after controlling for initial abilities. Students with high learning motivation demonstrated higher collaborative skill scores than students with low learning motivation. These results indicate that learning motivation positively contributes to students' participation, interaction, communication, and teamwork during the learning process.

3) Simultaneous interaction effect between Instructional models (PjBFL and direct instruction) and motivation for learning mathematics on collaborative skills and creative thinking

The third hypothesis examined whether instructional models (PjBFL vs. Direct Instruction) influence students' collaborative and creative thinking skills by interacting with mathematics learning motivation. Although the multivariate analysis revealed a statistically significant interaction effect, the effect appeared to be stronger for collaborative skills than for creative thinking. The graphical patterns also suggest that the practical magnitude of the interaction was relatively modest. Estimated marginal means showed that PjBFL was associated with higher levels of collaborative and creative thinking skills for highly motivated students, whereas the effect was less pronounced for low-motivation students, and Direct Instruction was less sensitive to motivation levels. These findings suggest that the effectiveness of PjBFL is influenced by students' motivational engagement because the model requires active participation, self-directed learning, and collaborative interaction. This implies that the successful implementation of PjBFL should be accompanied by strategies that support and enhance student motivation. These findings are consistent with previous studies reporting that project-based and flipped learning improve collaborative

interaction and higher-order thinking skills. However, compared with earlier studies that reported stronger effects, the present study showed more moderate improvements. This difference may be related to the shorter intervention period and the vocational school context, where students may require longer adaptation to student-centered learning environments [54, 55].

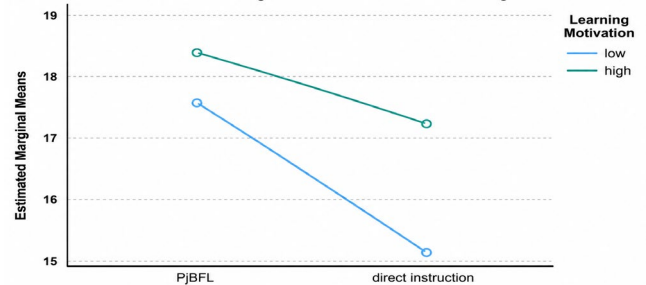


Fig. 5. Estimated marginal means of creative thinking skills among students with high and low learning motivation.

Fig. 5 shows that the estimated marginal means for creative thinking skills varied across instructional models and motivation levels. PjBFL produced higher scores than Direct Instruction at both motivation levels, whereas highly motivated students consistently outperformed those with low motivation. These results indicate the main effects of the learning model and motivation. Although the multivariate analysis identified an overall interaction effect, the univariate interaction effect for creative thinking was not statistically significant. This finding suggests that creative thinking is influenced more strongly by task characteristics and individual cognitive engagement than by the combined effect of instructional model and learning motivation.

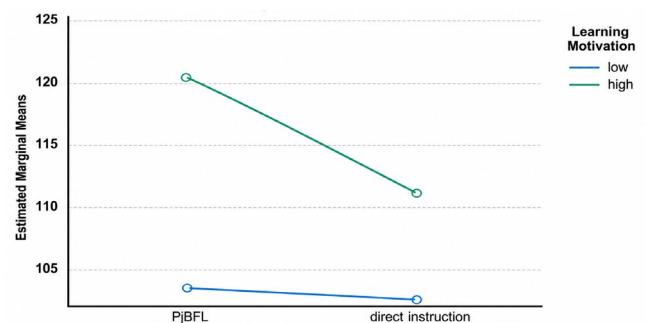


Fig. 6. Estimated marginal means of collaborative skills among students with high and low learning motivation.

Fig. 6 suggests that learning motivation strengthens students' engagement in collaborative activities, particularly in the PjBFL environment. Highly motivated students were more likely to participate actively in discussion, coordinate group responsibilities, and contribute during project completion, which may explain the higher collaborative skill performance observed in this group. PjBFL consistently produced higher scores than Direct Instruction at both motivation levels, with the largest differences occurring among highly motivated students, indicating that strong learning motivation maximizes the effectiveness of PjBFL. Overall, these findings highlight the importance of aligning instructional strategies with students' motivation to effectively support the development of both collaborative and higher-order thinking skills in mathematics learning.

4) *Interaction effect of instructional models (PjBFL and direct instruction) and learning motivation on creative thinking skills*

The fourth hypothesis examined whether instructional models (PjBFL vs. Direct Instruction) influence students' creative thinking skills through their interaction with mathematics learning motivation. The interaction between instructional model and learning motivation was not statistically significant for creative thinking. One possible explanation is that creative thinking is influenced more strongly by open-ended problem-solving tasks and opportunities for idea exploration than by the interaction between instructional model and learning motivation. These results imply that creative thinking in mathematics is primarily shaped by task characteristics such as open-ended problem solving, mathematical reasoning, and individual cognitive engagement rather than by the interaction of instructional model and motivation. While PjBFL and motivation independently contributed to creative thinking, their combination did not yield a synergistic effect. These findings are consistent with prior studies reporting limited or context-dependent interaction effects between instructional approaches and students' motivation on higher-order thinking skills [56, 57].

5) *Interaction effect of instructional models (PjBFL & direct instruction) and learning motivation on collaborative skills*

The fifth hypothesis examined whether instructional models (PjBFL vs. Direct Instruction) influence students' collaborative skills by interacting with mathematics learning motivation. The findings suggest that collaborative skills are more sensitive to students' motivational engagement than creative thinking skills. In the PjBFL environment, highly motivated students appeared more willing to participate actively in pre-class preparation, communicate with peers, coordinate group responsibilities, and contribute to collaborative problem-solving activities. These participation patterns likely strengthened collaborative interaction and group coordination during project activities. In contrast, students with lower motivation may have participated less consistently, thereby reducing the potential benefits of the PjBFL model. These findings indicate that the effectiveness of collaborative learning environments depends not only on instructional design but also on students' willingness to engage actively in group learning processes. The results are consistent with previous studies showing that motivational factors strengthen the effectiveness of student-centered and project-based learning environments [58].

This study has several limitations that should be considered when interpreting the findings. First, the study employed a quasi-experimental design with non-randomized group assignment, which may limit causal generalization. Second, the intervention was conducted in a single vocational school context, potentially limiting the broader applicability of the findings. Third, the relatively short intervention period may not have fully captured the long-term effects of PjBFL on collaborative and creative thinking development. Future studies are therefore recommended to involve more diverse educational contexts, longer intervention periods, and randomized experimental designs to further examine the sustainability and generalizability of the findings.

V. CONCLUSION

This study examined the effects of instructional models and learning motivation on collaborative skills and creative thinking in mathematics. The findings show that PjBFL is more effective than Direct Instruction in enhancing collaborative skills and creative thinking. In addition, students with higher levels of learning motivation consistently demonstrated stronger performance in both skill domains, highlighting the critical role of motivation in supporting meaningful learning processes.

This study demonstrates that the interaction between the instructional model and learning motivation operates differently across skill domains. Specifically, learning motivation strengthens the effectiveness of PjBFL in improving collaborative skills, whereas creative thinking has no significant interaction effect. This indicates that collaborative skills are more sensitive to the alignment between instructional strategies and motivational conditions, whereas instructional design tends to influence creative thinking more independently. These findings provide important empirical evidence on how instructional innovation and learner characteristics jointly shape collaborative and creative thinking skills in mathematics education.

From a practical perspective, teachers should not only implement PjBFL but also actively support the learning motivation of students, particularly those with lower motivation levels. This can be achieved through structured guidance, continuous formative feedback, and well-designed collaborative scaffolding during project-based activities. The findings emphasize the need for vocational schools to support technology-enhanced learning environments by ensuring access to digital learning platforms and reliable internet infrastructure. At the policy level, this study supports the integration of project-based and technology-supported instructional approaches into mathematics curricula to better foster collaborative and creative thinking skills relevant to future workplace demands.

Despite these contributions, several limitations should be acknowledged. First, the use of a quasi-experimental design with non-random group assignment limits the strength of causal inference. Second, the study was conducted within a specific institutional context, which may restrict the generalizability of the findings. Third, the intervention's relatively short duration may not fully capture the long-term development of students' collaborative skills and creative thinking.

Future research should address these limitations by employing randomized designs with larger and more diverse samples across different educational contexts. Further studies should also investigate the longitudinal impact of PjBFL, examine additional moderating variables such as self-regulated learning and digital literacy, and explore its implementation across different subject areas or interdisciplinary settings. Such efforts will deepen the understanding of how instructional strategies and learner characteristics interact to develop collaborative and creative thinking skills in students.

CONFLICT OF INTEREST

The authors declare that there are no financial, personal, or

professional relationships that could be understood as potential conflicts of interest in relation to this study.

AUTHOR CONTRIBUTIONS

Pascalian Hadi Pradana contributed to the formulation of research ideas, development of research design, implementation of data collection and analysis, and preparation of the initial draft of the manuscript. I Wayan Santyasa contributed to the development and validation of research instruments, as well as the review of methodological aspects and statistical analysis. I Made Teguh contributed to the interpretation of research results, in-depth discussion of findings, and editing of the manuscript. I Komang Sudarma was responsible for supervising the entire research process, ensuring academic quality, and conducting a final review and approval of the manuscript for publication.

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