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Flipped Classroom Integrates Problem-Based Learning: Enhancing Conceptual comprehension, Problem-Solving Abilities, and Self-Regulated Learning

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Abstract

Indonesian students' mathematical conceptual comprehension, problem-solving skills, and self-regulated learning (SRL) remain persistent challenges. National assessment data reveals that students' mastery of combinatorics—the core topic of this study—is only 24.64%, with average mathematics scores in South Kalimantan at 36.69, far below the expected standard. These deficiencies highlight the need for innovative instructional approaches that simultaneously address cognitive and metacognitive competencies. This research investigates the efficacy of a flipped classroom combined with problem-based learning (FC-PBL) in improving students' conceptual comprehension, problem-solving abilities, and self-regulated learning within the context of mathematics. This quasi-experimental study engaged 12th-grade students who were separated into experimental (FC-PBL) and control (PBL only) groups. Instruction on combinatorics was provided to both groups, with pre-test and post-test administered to assess three learning outcomes. The findings indicated notable enhancements in conceptual comprehension and problem-solving capabilities in the FC-PBL group compared to the control group, as evidenced by a Hotelling's T^2 test and a Mahalanobis distance of $D^2 = 1.72$. However, SRL did not exhibit a statistically significant difference, reinforcing that student-centered approaches alone are insufficient to foster self-regulation without explicit scaffolding. These results imply that while FC-PBL presents a viable method for promoting mathematical comprehension and problem-solving, its effect on SRL necessitates further instructional support. The research offers empirical backing for the fusion of flipped and problem-based methodologies to tackle conceptual and procedural gaps in mathematics education.

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INTRODUCTION

The cultivation of 21st-century skills, including conceptual comprehension, problem-solving abilities, and self-regulated learning, has emerged as a pivotal concern within contemporary educational frameworks worldwide (Morris-Eyton & Pretorius, 2023). Nevertheless, obstacles remain in mathematics instruction, especially in nurturing these

essential competencies. In Indonesia, national assessments reveal alarming patterns in students' mathematical skills. The *Tes Kemampuan Akademik* (TKA) 2025, a standardized academic assessment, provides direct evidence of these deficiencies. Nationally, the average mathematics score for senior high school students was only 37.03 out of a maximum score (Pusat Asesmen Pendidikan Kemendikdasmen, 2025). More critically, in South Kalimantan—the location of this study—students achieved an average mathematics score of 36.69, which remains far below the expected standard of proficiency (Pusat Asesmen Pendidikan Kemendikdasmen, 2025). The low TKA scores are further reflected in students' mastery of specific mathematical topics. According to recent diagnostic assessments, students' ability to understand, apply, and reason at a higher level regarding enumeration rules (including the addition rule, multiplication rule, permutations, and combinations)—the core topic of this study—was only 24.64%. This finding indicates that fewer than one in four students possess adequate competency in combinatorics. These findings highlight fundamental deficiencies in understanding concepts and solving problems. These performance metrics not only highlight a widespread shortfall in mathematical proficiency but also indicate more profound challenges in students' capacity to tackle intricate, real-world issues.

Indonesian students demonstrate considerable shortcomings in mathematical problem-solving, especially when faced with non-standard or contextual challenges. Recent research indicates that students often abandon tasks, default to guessing, or neglect to methodically analyze problems when confronted with unfamiliar formats (Himmawan & Kusumah, 2024). At the senior high school level, students struggle particularly with combinatorics problems. Research by Nursisto et al. (2022) found that students have difficulty distinguishing between permutation and combination concepts and often confuse which formula to apply. Furthermore, Salwa et al. (2025) identified that students' weak conceptual understanding leads to errors in selecting the appropriate counting rules (addition and multiplication rules) when solving contextual problems. The World Bank (2020) supports these conclusions, observing that numerous secondary graduates struggle to solve basic numeracy problems appropriate for their grade level, suggesting a systemic failure to cultivate problem-solving skills throughout their education. In addition to the difficulties in problem-solving, another significant factor contributing to students' poor performance is their fragile understanding of fundamental mathematical concepts. Equally alarming are the systematic deficiencies in conceptual comprehension. Verina and Juandi (2022) illustrate students' failure to link mathematical concepts with suitable visual or symbolic representations. Foundational weaknesses are evident even in primary education, where 50% of fourth-graders cannot order four-digit numbers, and 40% of second-graders do not recognize two-digit numerals (World Bank, 2020). Such inadequacies in basic number sense severely hinder the advancement of more complex mathematical skills (Decarli et al., 2023; Sintawati et al., 2020).

These prevalent issues regarding students' capacity for self-regulation and problem-solving are not exclusive to Indonesia; instead, they highlight a more extensive issue within mathematics education on a global scale. On a global scale, the National Council of Teachers of Mathematics (National Council of Teachers of Mathematic, 2000) highlights problem-solving as fundamental to mathematics education, insisting it should be integrated into all teaching experiences rather than regarded as a separate entity. Likewise, Tang et al. (2023) recognize problem-solving as an essential competency for tackling intricate real-world problems, stressing the importance of addressing these deficiencies in educational methodologies. Scholars and educators have reacted to these challenges by promoting innovative teaching practices that correspond with modern learning demands. For instance, Yang et al. (2021) assert that a solid conceptual comprehension is vital for effective

problem-solving, which calls for instructional frameworks that emphasize meaningful interactions with mathematical ideas. Concurrently, Gupta et al. (2024) underscore the significance of self-regulated learning in enabling students to take charge of their educational journeys, especially in contexts that necessitate independent study. Despite these suggestions, conventional lecture-based approaches frequently prevail in classrooms, restricting chances for engaging, student-focused learning (Gamo, 2022). This disconnect highlights the necessity for teaching models that merge active learning techniques with technology-enhanced education.

While flipped classroom (FC) leverages pre-class content delivery to maximize in-class problem-solving (Gonda et al., 2021), problem-based learning (PBL) structures learning around authentic collaborative inquiry (Hidajat, 2023). However, their combined potential remains underexplored. Lin (2019) found that FC notably improves academic performance, student motivation, and problem-solving skills. Similarly, PBL, which organizes learning around genuine problems and collaborative exploration (Hidajat, 2023), has been proven to enhance conceptual comprehension (Chesnais, 2021). However, existing research frequently analyzes these models separately, with insufficient investigation into their combined application. For example, while Al-Abdullatif (2020) noted enhanced self-regulated learning in FC settings, studies that merge FC's asynchronous format with PBL's collaborative problem-solving methods remain limited, especially within the context of Indonesia. While FC and PBL have been studied in isolation (Chesnais, 2021; Lin, 2019), no research has empirically tested their synergy in addressing Indonesia's dual challenges of conceptual and procedural deficits, particularly in the context of combinatorics learning at the senior high school level. The originality of this research resides in its fusion of FC and PBL, aiming to fill gaps in both theoretical and practical realms.

Theoretically, the FC-PBL approach supports the development of conceptual comprehension, problem-solving skills, and self-regulated learning (SRL) through a two-phase structure. In the pre-class phase, students engage with instructional videos and online quizzes to independently learn foundational concepts. This self-paced digital learning fosters SRL by requiring students to plan their study time, monitor their comprehension, and regulate their learning progress (Al-Abdullatif, 2020). In the in-class phase, collaborative problem-based learning activities encourage students to apply their pre-acquired knowledge to solve contextual problems. This active, inquiry-driven process promotes conceptual comprehension by requiring students to articulate, defend, and revise their understanding through peer discussion and enhances problem-solving skills by confronting them with authentic, non-routine tasks that demand strategic thinking and mathematical reasoning (Hidajat, 2023). Built on Flipped Learning Network (2014) four foundational components—flexible environment, learning culture, intentional content, and professional educators—this integrated model utilizes digital tools (e.g., online platforms) for pre-class conceptual investigations, followed by in-class PBL activities centered on collaborative problem-solving. This strategy aligns with National Council of Teachers of Mathematic (2000) focus on infusing problem-solving into everyday learning while promoting self-regulation through systematic independence. By connecting FC's technological benefits with PBL's inquiry-based approach, this study aspires to establish a vibrant learning environment that concurrently addresses the conceptual, procedural, and metacognitive aspects of mathematics education.

This research intends to examine the effects of a flipped classroom integrated with problem-based learning (FC-PBL) on students' conceptual comprehension, problem-solving skills, and self-regulated learning in mathematics, specifically in the context of combinatorics. Furthermore, it assesses the effectiveness of FC-PBL in comparison to traditional PBL to ascertain if the incorporation of flipped pedagogy enhances results in

these areas. Through this investigation, the study contributes to evidence-based approaches for maximizing 21st-century skill development in mathematics education.

METHODS

This research utilized a quasi-experimental framework to investigate the impact of a flipped classroom coupled with a problem-based learning (FC-PBL) method on students' grasp of concepts, problem-solving abilities, and self-regulated learning. The study employed a pretest-posttest control and experimental group design (Creswell, 2012), where the experimental group received the FC-PBL intervention while the control group was taught using standard PBL. Table 1 presents the structure of the research design.

Table 1 Structure of the pretest-posttest control group design

Group	Before Treatment			Treatment	After Treatment		
	Pretest		Questionnaire		Posttest		Questionnaire
E_1	AE_1	CE_1	OE_1	X	AE_1	CE_1	OE_1
E_2	AE_2	CE_2	OE2	Y	AE_2	CE_2	OE2

Time →

The experimental group (E_1) engaged in mathematics education through a flipped classroom approach combined with problem-based learning (X), whereas the control group (E_2) experienced traditional problem-based learning (Y). Both groups of students were evaluated with a concept understanding test (A), a mathematical problem-solving assessment (C), and a self-regulated learning survey (O) prior to and following the intervention.

The research compared an experimental group taught using FC-PBL with a control group that underwent traditional PBL instruction. Participants consisted of 12th-grade natural science students from public senior high schools in Tanah Laut Regency, South Kalimantan. Two intact classes were selected via purposive sampling based on the following criteria: (1) both classes had comparable mathematics achievement based on previous semester examination scores, (2) both classes followed the same curriculum and learning schedule, (3) both classes had access to the necessary digital devices and internet connectivity for the flipped classroom implementation, and (4) the mathematics teacher for both classes was the same to ensure instructional consistency. One intact class was then designated as the experimental group (FC-PBL) and the other as the control group (traditional PBL).

The experimental group (n = 36) participated in FC-PBL, which integrated pre-class digital materials with in-class PBL sessions, whereas the control group (n = 36) adhered to traditional PBL teaching methods. Both groups addressed the same curriculum content and learning goals to maintain equivalence. The research aimed to assess the learning outcome differences between the two instructional strategies, specifically regarding conceptual comprehension, problem-solving, and self-regulated learning skills.

This study was conducted through four main stages. Prior to the intervention, all research instruments were validated. The conceptual comprehension and problem-solving tests were validated through expert judgment, while the self-regulated learning questionnaire was validated through construct validity using factor analysis, yielding a KMO value of 0.763 and a significant Bartlett's test ($p < 0.001$). Reliability testing showed Cronbach's alpha values of 0.72 for conceptual comprehension (KR-21), 0.87 for problem-solving, and 0.89 for self-regulated learning, all indicating reliable instruments. In the first stage, a pretest was administered to both groups. In the second stage, over five meetings (every 90 minutes), the experimental group received FC-PBL instruction, where students accessed instructional videos and online quizzes via Desmos Classroom (enabling teacher

monitoring and progress tracking) before class, then engaged in collaborative problem-solving, group presentations, and teacher-led debriefing during class, while the control group received conventional PBL without pre-class video components. In the third stage, a posttest parallel to the pretest was administered to both groups. In the final stage, data analysis was conducted using descriptive and inferential statistics.

This methodological strategy provided a thorough assessment of the FC-PBL model's efficacy compared to standard PBL in improving students' conceptual comprehension, problem-solving, and self-regulated learning. Two distinct variables: (1) FC-PBL and (2) traditional PBL. The outcome variables were assessed across three areas: conceptual comprehension (including subcomponents Pk1 and Pk2), problem-solving abilities (Pm1 and Pm2), and self-regulated learning (KB1 and KB2). Table 2 illustrates the framework for evaluating these variables.

Table 2 The relationship between research variables

		Independent Variable	
		A FC-PBL (1)	PBL (2)
Dependent Variable	Conceptual Comprehension (Pk)	Pk1	Pk2
	Problem Solving (Pm)	Pm1	Pm2
	Self-Regulated Learning (KB)	KB1	KB2

To assess the variables of concept comprehension, problem-solving, and self-regulated learning, both pretests and posttests were administered. Descriptions are provided for understanding concepts and problem-solving tasks, while questionnaires are utilized for self-regulated learning. Combinatorics was selected as the instructional topic for this intervention, as it aligned with the school's curriculum schedule during the research period. The subsequent Table 3 outlines the indicators of concept comprehension, problem-solving, and self-regulated learning.

Table 3 The indicators of concept comprehension, problem-solving, and self-regulated learning

Indicators		
Conceptual Comprehension	**Problem Solving**	**Self-Regulated Learning**
Revealing the concepts used to solve the combinatorics question	Assess the sufficiency of the details required to address the issue	**Planning:** Setting educational objectives; Organizing study schedules; Identifying learning requirements
Specifies instances and not instances of events that include addition, multiplication, permutation or combination rules	Formulating a mathematical model based on the presented problem	**Self-control:** Educational programs; Perceiving obstacles as opportunities; Behavioral conduct
Connecting ideas related to enumeration guidelines.	Employing the correct equation	**Self-monitoring:** Tracking learning advancements; Observing the learning journey
Effectively apply permutation, combination, and slot filling formulas when addressing problems	Perform the counting task accurately.	**Self-reflection:** Assessing learning methods and results; Personal response to the outcomes of learning assessment

Conceptual Comprehension	Indicators Problem Solving	Self-Regulated Learning
	Providing answers in a systematic, comprehensive, and accurate manner.	
	Verifying the solution by substitution into the original equation / employing another valid approach.	

Note: Indicators for conceptual comprehension were adapted from Hershkowitz & Vinner (1989), Jin & Wong (2021), and Evans et al. (2023); problem-solving indicators were adapted from Polya (1973) and Säfström et al. (2023); self-regulated learning indicators were adapted from Zimmerman (1989) and Schunk (2020)

This research utilized two methods of data analysis, specifically descriptive and inferential analysis, to assess the impact of FC-PBL on students' conceptual comprehension, problem-solving abilities, and self-regulated learning. Descriptive statistics were employed to outline the features of the pretest and posttest data for both the experimental group (FC-PBL) and the control group (PBL).

The scoring categories for conceptual comprehension and problem-solving tests were adapted from Arikunto (2013), with a minimum passing standard of 75 applied in this study. A score below 75 indicates a lack of mastery and is categorized as "Need Improvement." The detailed categories are presented in Table 4.

Table 4 Scoring categories for conceptual comprehension and problem-solving ability

Score Interval	Category
$91 \leq x \leq 100$	Excellent
$83 \leq x \leq 91$	Good
$75 \leq x \leq 83$	Satisfactory
$x \leq 75$	Need Improvement

The scoring criteria for the self-regulated learning questionnaire were adapted from Widoyoko (2017), based on the calculation of ideal mean and ideal standard deviation, as presented in Table 5.

Table 5 Self-regulated learning questionnaire scoring criteria

Score Interval	Category
$x > 84$	Very High
$68 \leq x \leq 84$	High
$52 \leq x < 68$	Moderate
$36 \leq x < 52$	Low
$x \leq 36$	Very Low

The preliminary descriptive analysis provided initial insights into developmental differences between the experimental (FC-PBL) and control (PBL) groups. To rigorously examine the significance of these differences, a comprehensive multivariate analysis was conducted following these sequential steps using R statistical software (employing the MVN package for *multivariate normality tests* and *MANOVA* for hypothesis testing) (Baumeister et al., 2024; Clavel & Morlon, 2020; Finch, 2022). First, assumption testing was performed, including: multivariate normality (*Mardia's test, $\alpha = 0.05$*)(Elbouch et al., 2022), univariate

normality (*Shapiro-Wilk test*), and covariance matrix homogeneity (*Box's M test*) (Ahmad, 2021). To holistically capture the impact of the integrated FC-PBL model, this study employs multivariate analysis (*Hotelling's* T^2) alongside Mahalanobis distance (D^2) for effect size measurement. This approach allows for simultaneous evaluation of three dependent variables: conceptual comprehension, problem-solving skills, and self-regulated learning, thereby addressing the limitation of univariate analyses in prior works. The null hypothesis (H_0) posited no significant difference between groups, while the alternative hypothesis (H_1) suggested otherwise. In cases where H_0 was rejected, post-hoc *Bonferroni tests* (*adjusted* $\alpha = 0.0167$) were conducted to identify which specific variables contributed to the observed differences. Effect sizes were interpreted using established thresholds for Mahalanobis Distance: $D^2 > 1$ (large effect), $D^2 = 0.5$ (medium effect), and $D^2 = 0.25$ (small effect) (Zieliński & Więckiewicz, 2025).

RESULTS AND DISCUSSION

To summarize student performance in these three areas, a descriptive statistical analysis was conducted. The students' scores on conceptual comprehension, problem-solving, and self-regulated learning are shown in Table 6.

Table 6 Descriptive statistics of experimental and control groups across measured variables

Group	Descriptive Statistical Parameters	Conceptual Comprehension		Problem Solving		Self-Regulated Learning	
		Pre	Post	Pre	Post	Pre	Post
Experimental	Minimum	10	60	12.5	65	64	74.4
	Maximum	40	90	47.92	90	95.2	100
	Mean	25.21	77.92	34.46	75.31	81.53	88.03
	Median	25	80	33.33	75	82	88
	Std. Deviation	7.59	7.06	8.77	6.21	8.62	7.16
Control	Minimum	10	45	20.83	50	65.80	71.2
	Maximum	40	85	47.92	85.1	90.50	96.8
	Mean	25.20	67.4	34.83	66.84	81.54	86.82
	Median	30	70	33.33	65.9	82.40	87.2
	Std. Deviaton	8.72	10.01	8.21	9.36	6.604	6.64

Descriptive analysis revealed notable improvements in students' concept comprehension, problem-solving skills, and self-regulated learning after the intervention. In the experimental group, which experienced a flipped classroom integrated with problem-based learning, the average posttest scores increased by 52.71 (concept comprehension), 40.85 (problem-solving), and 6.5 (self-regulated learning). The control group, which received problem-based learning, also showed gains, though comparatively smaller. These results indicate that the FC-PBL may be more effective in enhancing students' conceptual comprehension, problem-solving skill, and self-regulated learning. After conducting the descriptive analysis, inferential tests were utilized to evaluate the statistical significance of the noted differences, beginning with tests of assumptions to confirm the reliability of the following analyses. The outcomes of the test for the multivariate normality assumption are shown in Table 7, which includes the skewness and kurtosis figures along with their respective *p-value*s.

Table 7 Results of multivariate normality test

Data	Group	Mardia's Test	
		Skewness	Kurtosis
Pretest	Control	g1p = 10.04 *p-value = 0.44*	g2p = -0.18 *p-value* = 0.85
	Experimental	g1p = 5.13. *p-value* = 0.88	g2p = -0.404 *p-value* = 0.69

Data	Group	Mardia's Test	
		Skewness	**Kurtosis**
Posttest	Control	g1p = 5.82 *p-value* = 0.83	g2p = -0.48 *p-value* = 0.63
	Experimental	g1p = 6.13 *p-value* = 0.804	g2p = -1.009 *p-value* = 0.31

Mardia's test demonstrated multivariate normality for both pretest (all *p-value* > 0.05) and posttest (all *p-value* > 0.05) data. These non-significant Mardia's test results (p > 0.05 for both pretest and posttest) confirm that the multivariate normality assumption was satisfied for both groups before and after the intervention. This fulfillment justifies the use of parametric multivariate tests, specifically *Hotelling's* T^2 and MANOVA, for subsequent hypothesis testing. After assessing normality, we examined the homogeneity of the covariance matrices with *Box's M test* in Table 8.

Table 8 Results of *Box's M test* for homogeneity

Data	Statistic	P-value
Pretest	$\chi^2 = 6.6295$	0.3565
Posttets	$\chi^2 = 9.519$	0.1464

Box's M test validated the assumption of equal covariance matrices for both datasets pretest ($\mathcal{X}^2$ = 6.6295, *p-value* = 0.3565) and posttest ($\mathcal{X}^2$ = 9.519, *p-value* = 0.1464), with all *p-values* surpassing the 0.05 threshold. These non-significant Box's M test results (p > 0.05 for both pretest and posttest) confirm that the assumption of equal covariance matrices was met. This indicates that the variance-covariance structures of the three dependent variables were equivalent between the experimental and control groups both before and after the intervention. Therefore, the use of *Hotelling's* T^2 and MANOVA for subsequent hypothesis testing is statistically justified, as unequal covariance matrices could otherwise inflate Type I error rates. As the assumptions for MANOVA have been satisfied, a MANOVA analysis may be conducted utilizing Hotelling's T^2 test. An examination of the pretest data was carried out to determine if there were significant differences in the abilities of the two groups. The posttest was administered to assess the distinctions between the experimental group and the control group. Hotelling's $\boldsymbol{T^2}$ results are listed in Table 9.

Table 9 Results of Hotelling's $\boldsymbol{T^2}$

Data	**Statistic**	***P-value***
Pretest	$T^2 = 0.023616$	0.999
Posttest	$T^2 = 36.822$	5.017e-08

The *Hotelling's* T^2 test indicated that there were no notable differences among the groups prior to the test (T^2 = 0.024, *p-value* = 0.999), confirming that the initial levels of conceptual understanding, problem-solving, and self-regulated learning were similar. Conversely, the analysis conducted post-intervention revealed significant multivariate effects (T^2 = 36.822, *p-value* < 0.00001), highlighting distinct outcomes between the flipped classroom with PBL and the traditional PBL groups. In light of these significant multivariate results, we performed post hoc Bonferroni-adjusted t-tests (α = 0.017, adjusted from 0.05 for three dependent variables) to investigate each learning component individually. These tests assessed whether the experimental group outperformed the control group in: (1) conceptual comprehension, (2) problem-solving abilities, and (3) self-regulated learning. Prior to conducting post hoc Bonferroni, we verified univariate normality for each dependent variable using *Shapiro-Wilk* tests. The summary of the results of the normality assumption test is listed in Table 10.

Table 6 Recapitulation of normality assumption test results

Group	Variable	*p-value*	Assumption of Normality
Control	Post-Conceptual Comprehension	0.4095	Fulfilled
	Post-Problem Solving	0.474	Fulfilled
	Post-Self Regulated Learning	0.567	Fulfilled
Experimental	Post-Conceptual Comprehension	0.085	Fulfilled
	Post-Problem Solving	0.881	Fulfilled
	Post-Self Regulated Learning	0.181	Fulfilled

The results indicated that all data were normally distributed. Therefore, a Bonferroni post hoc analysis was subsequently performed to examine pairwise differences (see Table 11).

Table 7 Results of the Bonferroni Post Hoc test

Dependent Variable	Mean of Independent Variable (Group)		Mean Difference (Pairwise Comparison)	*p-value*
	FCL-PBL	PBL		
Conceptual Comprehension	77.92	67.4	10.52	2.92e-05
Problem-Solving	75.31	66.84	8.47	0.00053
Self-Regulated Learning	88.03	86.82	1.21	0.54

Post hoc analyses (Bonferroni-adjusted α =0.017) showed FC-PBL significantly improved conceptual comprehension (*p-value*<0.00001; *p-value* < α) and problem-solving (*p-value*= 0.0005; *p-value* < α) compared to PBL. While self-regulated learning outcomes showed no significant difference (*p-value*= 0.54; *p-value* > α), FC-PBL maintained a slight average lead of 1.21 points.

The influence of the intervention on the aggregated dependent variables (conceptual comprehension, problem-solving skills, and self-regulated learning) was assessed by utilizing Mahalanobis distance (D^2) in R-Studio. According to the classification, the resulting D^2 score of 1.72 (D^2>1) signifies a substantial effect size. This noteworthy magnitude indicates that FC-PBL led to considerably different multivariate learning results in comparison to traditional PBL, with particularly strong impacts noted for conceptual comprehension and problem-solving skills, although the effects on self-regulated learning were less marked.

This research illustrates that the combination of FC-PBL notably enhances students' grasp of concepts and their mathematical problem-solving skills, whereas its influence on SRL does not reveal any significant variation. These results directly tackle the research issue outlined in the introduction, specifically how the FC-PBL approach can act as a remedy for inadequate conceptual comprehension, insufficient problem-solving abilities, and less than ideal student self-regulated learning in Indonesia, as evidenced by PISA and TIMSS statistics (Mullis et al., 2019; OECD, 2023). Alongside the results from the multivariate *Hotelling's* T^2 test that reveal significant differences between the experimental and control groups following the intervention, this outcome is additionally reinforced by a *Mahalanobis distance* value of $D^2 = 1.72$ ($D^2 > 1$), which signifies a notable multivariate effect. This considerable effect implies that the FC-PBL model influences not just one variable but also brings about significant changes across the interconnected areas of conceptual ability, problem-solving, and SRL.

The effectiveness of FC-PBL in enhancing conceptual comprehension and problem-solving abilities can be attributed to two key instructional features. First, the pre-class phase requires students to engage with instructional videos and online quizzes independently. This self-paced exposure to foundational concepts allows students to build initial understanding before entering the classroom, reducing cognitive load during face-to-face

sessions and enabling more focused attention on complex problem-solving (Al-Abdullatif, 2020). Second, the in-class phase employs collaborative problem-based learning, where students work in small groups to solve contextual combinatorics problems, present their solutions, and participate in teacher-led debriefing. This structure promotes active negotiation of meaning and peer scaffolding, which are essential for deepening conceptual understanding (Hidajat, 2023). Future research can replicate this model by implementing (1) pre-class asynchronous activities using a digital platform (e.g., Desmos Classroom) with monitoring features, (2) in-class collaborative problem-solving sessions lasting 90 minutes per meeting, and (3) structured debriefing sessions to address student misconceptions and reinforce correct solution strategies.

Conceptually, the flipped classroom enables students to independently gain foundational knowledge through instructional videos prior to in-person sessions. This is in line with the Flipped Learning Network (2014) and the assertions made by Yang et al. (2021), which highlight the necessity of early engagement with content to promote a deeper understanding of concepts. Evidence supporting the enhancement of conceptual understanding is also provided by Aboraya (2021) & Sulistyowati et al., (2024), who demonstrated that FC aids in reducing comprehension disparities among students, particularly concerning abstract mathematical concepts. The effectiveness of FC is further amplified when combined with PBL, as problem-based learning fosters the application of concepts in real-world collaborative settings, promoting the development of higher-order thinking. This aligns with the findings of Aba-Oli et al., (2025) & Munawaroh et al., (2024), who determined that PBL is beneficial in improving students' HOTS skills, such as mathematical reasoning and problem-solving.

Nevertheless, in spite of statistically significant enhancements, the average post-intervention scores for conceptual understanding (77.92) and problem-solving (75.31) still fall within the "Satisfactory" range according to the classification scale ($75 \leq x \leq 83$). This can be attributed to the very low initial pretest scores (refer to Table 6), showing that while there was a substantial improvement in learning outcomes, students still need additional time and support to attain the "Good" category (>83). These results indicate that FC-PBL is effective in fostering foundational growth but is not sufficient on its own to reach high performance levels without further interventions such as metacognitive scaffolding, extended content exposure, or enrichment with reflective content.

Meanwhile, the absence of a notable distinction in self-regulated learning (SRL) casts doubt on the effectiveness of the implemented strategy in genuinely fostering students' regulatory capacities. This shortcoming is underscored by the quantitative findings, which reveal only a trivial advantage for the experimental group (pretest 81.53, posttest 88.03) over the control group (pretest 81.54, posttest 86.82). Such marginal gains call into question the substantive value of the intervention itself. The relatively high baseline SRL scores across both groups, rather than signaling a ceiling effect, may instead expose the intervention's inability to meaningfully advance self-regulatory competencies beyond what students already possessed. Crucially, this outcome aligns with a growing body of literature suggesting that SRL does not automatically improve through student-centered instructional formats alone. As Alvarez et al. (2022) and Silva et al. (2023) critically emphasize, the development of SRL demands deliberate and systematic scaffolding—such as structured reflection, self-monitoring, and metacognitive prompting—elements notably absent or insufficiently integrated in many flipped classroom implementations. Without such intentional design, as Torres-Martín et al. (2022) similarly caution, the pedagogical claims surrounding flipped or student-centered approaches risk being overstated. Indeed, prior studies have shown that SRL gains are not inherently tied to instructional models but rather to the explicit cultivation of self-regulatory skills, the absence of which often results in

nonsignificant differences between experimental and control conditions (Al-Abdullatif, 2020; Hidajat, 2023). The present findings, therefore, add to the critical consensus that simply altering instructional delivery is insufficient; without embedded, structured support for self-regulation, such interventions are unlikely to produce the measurable improvements in SRL that they purport to achieve.

Based on prior research and the findings presented, it can be inferred that FC-PBL serves as a valuable educational approach to tackle conceptual and problem-solving difficulties within Indonesian mathematics education, as mentioned in the introduction. Nonetheless, to effectively address the challenge of students' insufficient learning independence as described in this research, the FC-PBL method should be enhanced with scaffolding elements that specifically aid in the development of SRL. With this enhancement, FC-PBL is more likely to facilitate a thorough and enduring transformation in future educational experiences. While this study provides promising evidence for the effectiveness of FC-PBL, several aspects can be improved in future research. First, this study employed a quasi-experimental design with intact classes, which reflects natural classroom conditions. Future studies may employ a randomized controlled trial to strengthen causal claims about the effectiveness of FC-PBL. Second, the sample was limited to 12th-grade students in Tanah Laut Regency, South Kalimantan. Future research could expand the sample to multiple schools across different provinces or different grade levels to test the generalizability of the findings

CONCLUSION

The findings of this research affirm that the combination of FC-PBL significantly improves students' conceptual comprehension and their ability to solve mathematical problems. These results support the identified research issue concerning the necessity to rectify both conceptual and procedural deficiencies in Indonesian mathematics education. The implementation of FC-PBL resulted in notably better posttest results in understanding concepts and solving problems when compared to conventional PBL, as demonstrated through multivariate analysis. Nevertheless, the lack of a significant difference in SRL outcomes suggests that the intervention on its own may not be enough to fully foster autonomy in learning. This underscores the importance of integrating additional scaffolding techniques such as guided reflection, monitoring of learning progress, and self-assessment tools to enhance the development of SRL. Consequently, while FC-PBL is shown to be an effective teaching method for improving mathematical skills, it needs further refinement to adequately bolster students' self-regulated learning. The FC-PBL design did not include explicit SRL scaffolds, suggesting an opportunity for future studies to integrate such strategies.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

RNH; Conceptualization, Writing - Original Draft, and Editing. DW; Validation and Supervision.

AI DISCLOSURE STATEMENT

The author used QuillBot to help improve the language and grammar of this manuscript. All suggestions generated by the tool were carefully reviewed and edited by the author. Apart from this language assistance, no other artificial intelligence (AI) tools were used in the research, analysis, writing, or preparation of this study.

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