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Collaborative problem solving vs problem-based learning and cognitive styles on students' problem-solving skills and mathematical reasoning abilities

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Abstract

Background: Indonesia continues to face persistent challenges in students' mathematical problem-solving and reasoning abilities, as reflected in declining international assessment results. These issues indicate a need for instructional strategies that more effectively cultivate higher-order thinking. CPS and PBL are widely used approaches, yet their combined effects with cognitive styles remain underexplored.
Aim: This study aims to compare the effectiveness of Collaborative Problem Solving (CPS) and Problem-Based Learning (PBL) on problem-solving and mathematical reasoning abilities, and to examine the role of Field-Independent (FI) and Field-Dependent (FD) cognitive styles, including their interaction with instructional strategies.
Method: A quasi-experimental 2×2 factorial design was implemented with 119 seventh-grade students assigned to CPS or PBL and classified into FI or FD groups using the GEFT instrument. Data on problem-solving and reasoning were collected through validated essay tests. MANOVA was used to analyze main and interaction effects.
Results: CPS produced significantly higher gains than PBL in both problem-solving and reasoning. FI students outperformed FD students across both strategies. A significant interaction effect was found, showing that FI learners benefit most from CPS, whereas FD learners perform relatively better under PBL, although still below FI peers.
Conclusion: CPS offers a more structured and effective pathway for developing higher-order mathematical thinking. Cognitive style strongly influences learning outcomes, highlighting the need for differentiated support. Instructional designs that integrate structured collaboration and cognitive-style profiling are recommended to optimize students' mathematical problem-solving and reasoning abilities.

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INTRODUCTION

The rapid development of 21st-century technology has accelerated human civilization and transformed the landscape of education. Learning is no longer confined to traditional, teacher-centered activities; instead, technological affordances encourage students to engage actively, construct meaning, and solve complex problems (Trilling & Fadel, 2009; Voogt & Roblin, 2019). Within the 21st Century Partnership Learning Framework, problem-solving competence is identified as a core skill necessary for navigating global challenges effectively (P21, 2019; Alismail & McGuire, 2015). Problem-solving and reasoning, as emphasized by NCTM (2000), enable students to utilize facts, skills, and information strategically to solve non-routine tasks (Krulik, Rudnick, & Milou, 2003).

Despite its importance, students continue to struggle with problem-solving, particularly when faced with non-routine or ill-structured problems that require higher-order thinking (Jonassen, 2004; Ge, Law, & Huang, 2016). Research shows that students often misinterpret problems, fail to

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identify known and unknown elements (Saleh et al., 2016), and encounter difficulties communicating solutions effectively (Sumaji et al., 2019). These weaknesses reflect classroom practices that still emphasize procedural and routine exercises rather than reasoning-based tasks (Mabilangan et al., 2011; Dewi & Retnawati, 2023). International assessments echo this concern. Indonesia's PISA performance shows persistent decline, with mathematics scores decreasing from 386 (2015) to 376 (2018), placing Indonesian students in the low proficiency category (OECD, 2019, 2020). Recent analyses attribute this trend to insufficient exposure to higher-order thinking and problem-solving activities in school mathematics (Retnawati et al., 2022).

To address these challenges, the literature highlights Problem-Based Learning (PBL) as a constructivist strategy that helps students solve real-world problems by building on prior knowledge (Shoimin, 2014). Recent studies confirm its effectiveness in enhancing problem-solving, reasoning, and critical thinking (Argaw et al., 2017; Celik et al., 2020; Syahrial et al., 2021). However, PBL implementation is not without limitations. Scholars note inequitable task distribution, limited applicability across subjects, and challenges in accommodating differences in students' abilities (Lobo, 2016; Gunawan et al., 2020). These limitations highlight the need for more interactive learning models. Collaborative Problem Solving (CPS), grounded in Vygotsky's social constructivism, offers a promising alternative by engaging two or more learners in negotiating meaning, sharing strategies, and co-constructing solutions (OECD, 2017; Fiore, 2017). Evidence suggests that CPS enhances students' reasoning, communication, and problem-solving performance (Lin, Mills, & Ifenthaler, 2015; Harding et al., 2017; Chung et al., 2020). Through knowledge construction and knowledge transformation processes (Wiltshire et al., 2014; Fiore et al., 2010), CPS fosters deeper understanding, especially when learners face non-routine mathematical tasks.

Beyond instructional strategies, student characteristics particularly cognitive style play a critical role in learning outcomes (Bloom, 1982; Reigeluth, 1999). Cognitive style, defined as an individual's consistent way of processing information (Witkin & Goodenough, 1981), is a significant predictor of performance across disciplines (Khodadady et al., 2016; Chrysostomou et al., 2015). The distinction between Field-Dependent (FD) and Field-Independent (FI) learners offers meaningful insight into how students perceive, structure, and respond to mathematical problems (Witkin et al., 1977). Recent studies show that FI learners tend to outperform FD learners in problem-solving due to their analytical focus and independence, while FD learners require more scaffolding and contextual support (Sirin & Guzel, 2006; Gholami & Bagheri, 2012; Sudarman et al., 2016; Yudiernawati et al., 2014; Hanifah & Nuraeni, 2021). Recent studies have increasingly emphasized the importance of higher-order thinking skills particularly problem-solving and mathematical reasoning in preparing students for the demands of 21st-century learning. Existing research highlights that instructional models such as Problem-Based Learning (PBL) and Collaborative Problem Solving (CPS) can improve students' critical thinking, representation, and problem-solving abilities. Several recent works (e.g., Chung, Chen, & Ge, 2020; Retnawati et al., 2022; Dewi & Retnawati, 2023) demonstrate that technology-enhanced collaboration and inquiry-based environments promote deeper understanding and more effective knowledge construction. However, despite these advances, most prior studies examine PBL and CPS independently, not as an integrated instructional design. Moreover, existing research has rarely explored how these strategies interact with learner characteristics particularly cognitive style (Field-Dependent and Field-Independent) which has been shown to significantly influence students' reasoning and achievement. Current literature still lacks empirical evidence on how FD and FI learners respond differently when PBL is combined with CPS, especially in solving non-routine mathematical problems that require both individual reasoning and collaborative knowledge transformation. This gap becomes more evident considering Indonesia's consistently low PISA performance, which indicates unresolved issues in students' ability to solve ill-structured problems.

To address these limitations, the present study positions itself as an advancement of the state of the art by proposing an integrated PBL–CPS instructional model that leverages both individual and collaborative cognitive processes in mathematical problem solving. This design is grounded in contemporary research highlighting the need for hybrid pedagogical frameworks that simultaneously promote knowledge construction, negotiation of meaning, and shared reasoning. While previous studies confirm the separate effectiveness of PBL and CPS, no research has systematically examined their combined impact on mathematical reasoning and problem-solving when moderated by cognitive style. By incorporating cognitive style as a key differentiating variable, this study extends the existing body of knowledge and contributes a more nuanced understanding of how learners with different cognitive preferences benefit from collaborative and inquiry-based learning contexts.

The novelty of this research lies in its dual theoretical and practical contributions: (1) developing and testing an integrated PBL–CPS learning model that has not been empirically validated in previous mathematics education research, and (2) examining how this combined model interacts with Field-Dependent and Field-Independent cognitive styles in shaping students' reasoning and problem-solving abilities. This approach offers a new perspective on personalized and collaborative mathematics instruction, highlighting how instructional design can be adapted to accommodate diverse learners. The study not only fills a critical research gap but also provides a scalable pedagogical innovation that aligns with the demands of 21st-century competencies and addresses persistent weaknesses observed in national and international assessments.

METHOD

This study is a quasi-experimental research with a factorial 2x2 design. The researcher selected subject groups through random assignment to treatment, meaning the groups were chosen based on pre-existing classes at the school (Setyosari, 2015). The subjects of this research were drawn from the population of all seventh-grade students at SMPN 1 Way Serdang. Four classes were randomly selected as the research samples.

Table 1. showing the distribution of research subjects

Class	Treatment	Total		
		Female	Male	n
VII B	*Collaborative problem solving*	14	16	30
VII C		14	16	30
VII A	*Problem-based learning*	16	13	29
VII D		13	17	30
Total (N)		57	62	119

The data collection method used in this study was through testing techniques. The problem-solving ability test consisted of a written essay format with a total of 5 questions. A pilot test of the problem-solving ability test was conducted with 27 students. The validity index used was a correlation of ≥ 0.30 (Fraenkel, Wallen, & Hyun, 2014). The results of the calculations regarding the validity of the instrument items, assisted by SPSS 25, are described as follows:

Tabel 2. The output for the validity test

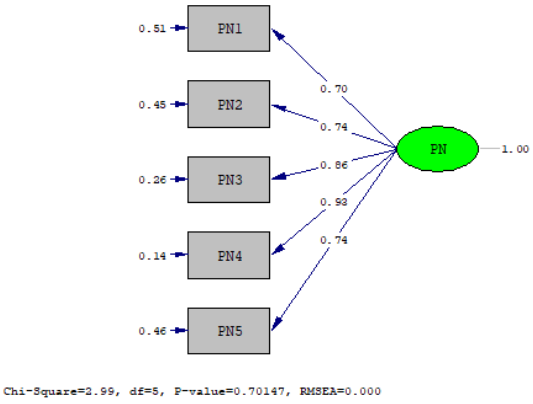
Correlations	Question				
	Question 1	Question 2	Question 3	Question 4	Question 5
Pearson Correlation	.523	.776	.876	.582	.876
N	27	27	27	27	27

The reliability test in this study used the calculation results from Cronbach's Alpha. The reliability index is ($\alpha \geq 0.70$)(Fraenkel et al., 2014).

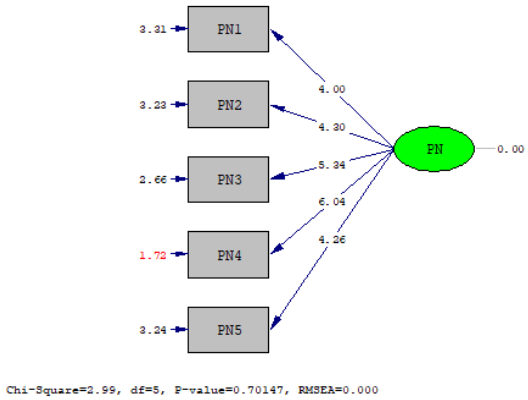
Tabel 3. The output for the reliability test

Reliability Statistics	
Cronbach's Alpha	N of Items
.823	5

The mathematical reasoning ability test consists of a written essay format with a total of 5 questions. A pilot test of the mathematical reasoning ability test involved 27 students. The results of the calculations using Confirmatory Factor Analysis (CFA) assisted by the Lisrel program regarding the validity of the instrument items are described as follows.



Picture 1. Output Standardized Solution



Picture 2. Output T-Value

Table 4. Summary of CFA Results

FIT INDEKS	ESTIMATED RESULT	CUT-OFF CRITERIA	FIT LEVEL
Chi-Square χ^2	p-value = 0,70	p-value > 0,05	Good
Relative χ^2	χ^2 = 2,99 dan df = 5	χ^2 < 2df	Good
RMSEA	0,0	< 0,06	Good
GFI	0,96	>0,90	Good
AGFI	0,87	>0,80	Good
SRMR	0,034	<0,08	Good
CFI	1,00	>0,90	Good

Indicators are considered valid if they meet the following criteria:

1. All indicators have SFL scores > 0.40.
2. The calculated t value for each indicator > 2.05.

Table 5. SFL Output Results

Indicator	SFL	Criteria	Decisions
PN1	0,70	>0,40	to meet the criteria
PN2	0,74	>0,40	to meet the criteria
PN3	0,86	>0,40	to meet the criteria
PN4	0,93	>0,40	to meet the criteria
PN5	0,74	>0,40	to meet the criteria

Tabel 6. The t-value Output Results

Indicator	*t-value*	Criteria	Decisions
PN1	4,00	>2,05	to meet the criteria
PN2	4,30	>2,05	to meet the criteria
PN3	5,34	>2,05	to meet the criteria
PN4	6,04	>2,05	to meet the criteria
PN5	4,26	>2,05	to meet the criteria

Based on the results in Table 3.13 and Table 3.14, all indicators have SFL > 0.40 and t > 2.05, so it can be concluded that the indicators of the mathematical reasoning ability variable are valid. Werts, Linn, and Joreskog (1974) recommend the following formula for calculating reliability:

$$CR = \frac{(\sum_I^P \lambda ij)^2}{(\sum_I^P \lambda ij)^2 + \sum_I^P V(\delta i)}$$

Table 7. Summary of Standardized Solution Results

Indicator	Std. Solution	Erors
PN1	0,70	0,51
PN2	0,74	0,45
PN3	0,86	0,26
PN4	0,93	0,14
PN5	0,74	0,46
Amount	3,97	1,82

$$CR = \frac{(3,97)^2}{(3,97)^2 + 1,82} = \frac{15,76}{(15,76) + 1,82} = \frac{15,76}{17,58} = 0,89$$

Based on the calculation results, a CR value of 0.92 was obtained. Since the CR value is greater than 0.70 (0.92 > 0.70), it can be concluded that the mathematical reasoning ability test has a high reliability index.

The cognitive style test instrument for students uses the Group Embedded Figure Test (GEFT), developed by Witkin, Oltman, Raskin, & Karp (1971). Student cognitive style data is collected using this instrument, known as the Group Embedded Figure Test (GEFT). The test is completed within a specified time, and all participant answers are reviewed and scored according to GEFT criteria, with a score of 1 for correct answers and 0 for incorrect answers. The maximum possible score is 18, while the minimum is 0. Classification of students into field dependence (FD) or field independence (FI) groups is based on the total score obtained. If the total score falls between 0-9, the student is categorized as field dependent (FD), and if the total score is between 10-18, the student is categorized as field independent (FI). Garton, Dyer, & King (2000) used the Spearman-Brown formula to demonstrate the reliability of GEFT at 0.82.

Table 8. Research Subjects Based on Cognitive Style Test Results

Cognitive style criteria		Learning Strategies		Total
		Collaborative Problem Solving	*Problem Based Learning*	
Cognitive style	Field-dependence	32	33	65
	Field-independence	28	26	54
Total		60	59	119

Based on Table 3.16, it is known that there are 65 subjects classified with a field-dependent (FD) cognitive style, while there are 54 subjects classified with a field-independent (FI) cognitive style. In this study, the data analysis used is a two-way Multivariate Analysis of Variance (MANOVA). According to Tuckman (1999),two-way MANOVA allows researchers to simultaneously examine the effects of multiple independent variables on the dependent variable.

RESULTS AND DISCUSSION

RESULTS

This process involves calculating and describing data based on learning strategies and cognitive styles using descriptive statistics, which include mean and standard deviation. Furthermore, hypothesis testing in accordance with parametric statistics adopted the Multivariate Analysis of Variance (Manova), while the prerequisite tests utilized the normality (Kolmogorov-Smirnov) and homogeneity approaches (Levene).

Table 9. The Results from the Normality Approach Using the Kolmogorov-Smirnov Test

	Mean	Std. Deviation	n	Statistic	p
Problem solving	66,875	11,344	56	.102	.200
Reasoning	76,535	8,576	56	.098	.200

Table 10. The Results from the Homogeneity Approach Using the Levene Test

Levene statistic	df1	df2	p
.358	3	105	.784

The hypothesis test is formulated in accordance with the sequence of MANOVA analysis, namely the analysis of differences between groups simultaneously, as presented in Table 4.11, and the main effects presented in Table 4.12 (examining the significance of each factor on the dependent variable). Hypothesis testing is determined by observing the significance level of < 0.05.

Table 11. Multivariate Analysis Results

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercep	Pillai's Trace	.992	6184.689[b]	2.000	104.000	.000
	Wilks' Lambda	.008	6184.689[b]	2.000	104.000	.000
	Hotelling's Trace	118.936	6184.689[b]	2.000	104.000	.000
	Roy's Largest Root	118.936	6184.689[b]	2.000	104.000	.000
Instructional Strategy	Pillai's Trace	.351	28.134[b]	2.000	104.000	.000
	Wilks' Lambda	.649	28.134[b]	2.000	104.000	.000
	Hotelling's Trace	.541	28.134[b]	2.000	104.000	.000
	Roy's Largest Root	.541	28.134[b]	2.000	104.000	.000
Cognitive Style	Pillai's Trace	.533	59.384[b]	2.000	104.000	.000
	Wilks' Lambda	.467	59.384[b]	2.000	104.000	.000
	Hotelling's Trace	1.142	59.384[b]	2.000	104.000	.000
	Roy's Largest Root	1.142	59.384[b]	2.000	104.000	.000
Instructional Strategy* Cognitive Style	Pillai's Trace	.107	6.212[b]	2.000	104.000	.003
	Wilks' Lambda	.893	6.212[b]	2.000	104.000	.003
	Hotelling's Trace	.119	6.212[b]	2.000	104.000	.003
	Roy's Largest Root	.119	6.212[b]	2.000	104.000	.003

a. Design: Intercept + InstructionalStrategy + CognitiveStyle + InstructionalStrategy * CognitiveStyle

b. Exact statistic

In the row for the learning strategies, the significance level was tested using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. All tests showed a significance value of 0.000 ($p < 0.05$). Therefore, H0 is rejected, and it can be concluded that there is a difference in problem-solving and reasoning skills between the two learning strategies, CPS and PBL. In the row for cognitive styles, the significance level was tested using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. All tests showed a significance value of 0.000 ($p < 0.05$). Therefore, H0 is rejected, and it can be concluded that there is a difference in problem-solving and reasoning skills between the two cognitive styles, FI and FD. In the row for the interaction between learning strategies and cognitive styles, the significance level was tested using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root.

All tests showed a significance value of 0.003 ($p < 0.05$). Therefore, H0 is rejected, and it can be concluded that there is an interaction between the learning strategies (CPS and PBL) and cognitive styles (FI and FD) on problem-solving and reasoning skills. Subsequently, the results of the dependent and independent variable tests (Tests of Between-Subjects Effects) in MANOVA are presented in Table 4.12.

Table 12. Tests of Between-Subjects Effects

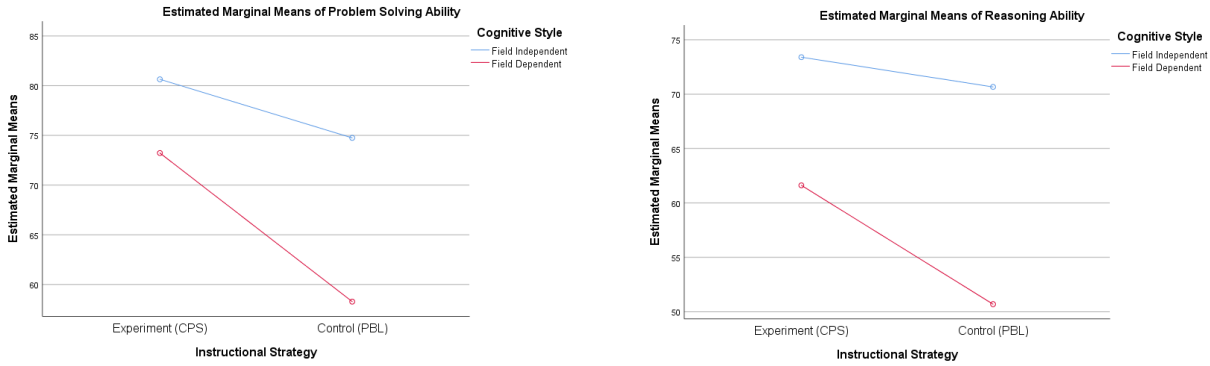
Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Reasoning Ability	8551.343[a]	3	2850.448	28.617	.000
	Problem Solving Ability	7500.711[b]	3	2500.237	41.595	.000
Intercep	Reasoning Ability	442869.694	1	442869.694	4446.102	.000
	Problem Solving Ability	554600.240	1	554600.240	9226.536	.000
Instructional Strategy	Reasoning Ability	1256.690	1	1256.690	12.616	.001
	Problem Solving Ability	2926.424	1	2926.424	48.685	.000

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Cognitive Style	Reasoning Ability	6798.569	1	6798.569	68.253	.000
	Problem Solving Ability	3845.172	1	3845.172	63.970	.000
Instructional Strategy*	Reasoning Ability	451.963	1	451.963	4.537	.035
Cognitive Style	Problem Solving Ability	553.089	1	553.089	9.201	.003
Error	Reasoning Ability	10458.895	105	99.609		
	Problem Solving Ability	6311.472	105	60.109		
Total	Reasoning Ability	457193.000	109			
	Problem Solving Ability	567692.000	109			
Corrected Total	Reasoning Ability	19010.239	108			
	Problem Solving Ability	13812.183	108			

a. R Squared = .450 (Adjusted R Squared = .434)
b. R Squared = .543 (Adjusted R Squared = .530)



Picture 3. Estimated Marginal Means of problem solving and reasoning ability

The interaction graph shows that the two lines are not parallel (will intersect) thus strengthening the results of the Manova test which shows that there is an interaction between learning strategies (CPS and PBL) and cognitive styles (FI and FD) on students' problem-solving and mathematical reasoning abilities.

Discussion

The findings of the first hypothesis show that the Collaborative Problem-Solving (CPS) strategy is more effective than the Problem-Based Learning (PBL) strategy in improving students' mathematical problem-solving abilities. The novelty of this result lies in demonstrating that the structured and iterative phases of CPS—problem clarification, idea generation, negotiation of strategies, planning, and joint implementation create more explicit reasoning pathways than the less scaffolded processes in PBL. While previous studies acknowledge the benefits of CPS for collaboration, creativity, or communication, few have directly compared CPS and PBL in the context of non-routine mathematical tasks, especially with a detailed phase-based implementation. This study provides empirical evidence that the phase structure of CPS yields superior gains in problem-solving performance.

From a theoretical standpoint, CPS aligns strongly with Vygotsky's sociocultural theory, particularly the concepts of the Zone of Proximal Development (ZPD) and scaffolding. Throughout the CPS phases, students jointly construct understanding through peer interaction, share partial ideas, and negotiate competing solution paths. These interactions function as social scaffolds that move students through their ZPD toward higher-level reasoning. The teacher's timely input further reinforces these scaffolds by providing "just-in-time" support. In contrast, PBL typically presents contextual problems but offers less explicit structuring of collaborative reasoning processes, making the internalization of strategies less systematic. This theoretical distinction helps explain why CPS

produced higher performance in this study even though PBL has been widely reported to outperform traditional instruction in improving problem-solving and critical thinking (Hidayat & Saragih, 2020; Nurhayati et al., 2022).

The superiority of CPS in this study is also related to the nature of the tasks used—non-routine, heuristic problems requiring integration of concepts, representation, and strategic decision-making. In such tasks, collaborative reasoning enables students to pool complementary knowledge and compensate for individual cognitive limitations. Recent empirical evidence supports this mechanism, showing that structured collaborative approaches significantly enhance problem-solving performance compared to individual PBL or loosely structured group work (Chang et al., 2021; Sahin & Adiguzel, 2023; Wang & Lim, 2024). This study contributes uniquely by demonstrating that when CPS is implemented with systematic phases and supported by timely scaffolding, it outperforms PBL in facilitating mathematical problem solving at the secondary level.

Overall, the results clarify that CPS is not merely another collaborative model but a structured, theoretically grounded strategy that explicitly supports reasoning processes. This provides an important scientific contribution: a phase-to-skill mapping showing how each CPS phase directly supports the cognitive operations required in mathematical problem solving. Such explicit alignment has been largely absent in previous comparative studies between CPS and PBL.

The findings of the second hypothesis indicate that Field-Independent (FI) students demonstrate significantly higher problem-solving performance than Field-Dependent (FD) students. This result aligns with the theoretical view that FI learners possess stronger abilities in analytical processing, internal referencing, and cognitive restructuring, all of which are essential components of mathematical problem solving (Witkin et al., 1977). FI students tend to process information autonomously, breaking complex problems into manageable elements, which enhances their capacity to construct solution pathways without relying heavily on external cues (Tinajero & Páramo, 2019).

Recent research continues to support this cognitive advantage. Studies in mathematics education show that FI learners have higher proficiency in generating strategies, interpreting abstract representations, and adapting to unfamiliar task structures, leading to superior performance on non-routine problems (Kozhevnikov et al., 2022). Similarly, Ramli et al. (2023) found that FI students outperform FD peers in multi-step reasoning tasks because FI individuals employ deeper metacognitive monitoring and are more flexible in switching strategies when initial attempts fail. These characteristics align closely with the demands of mathematical problem solving, which requires sustained reasoning, refinement of approaches, and the evaluation of multiple solution possibilities.

Conversely, FD students often rely more on external structure and teacher guidance, making them less comfortable in open-ended or ill-structured mathematical tasks (Zhang & Liu, 2021). FD learners also exhibit lower tolerance for cognitive ambiguity and tend to favor concrete, guided tasks, which limits their ability to construct independent solution paths. This cognitive style difference explains why FD students generally require more scaffolding, modeling, and prompts to reach the same level of performance as FI students.

Taken together, these findings reinforce the theoretical expectation that cognitive style strongly influences mathematical problem-solving ability, and they highlight the importance of differentiating instruction to accommodate FI and FD learners. By recognizing these cognitive characteristics, educators can design learning environments that support FD students more effectively while maximizing the problem-solving strengths of FI students.

The results of third hypothesis reveal a significant interaction between learning strategies (CPS and PBL) and cognitive styles (FI and FD) in determining students' mathematical problem-solving

performance. This interaction suggests that the effectiveness of a learning model is not uniform across students but is shaped by learners' cognitive tendencies. Specifically, FI students showed the highest gains when engaged in CPS, while FD students achieved relatively better outcomes under PBL, although their overall performance remained lower than their FI counterparts. These findings reinforce the perspective that instructional models must be aligned with cognitive characteristics to optimize learning outcomes (Tinajero & Páramo, 2019).

FI students thrive in CPS because the model emphasizes independent exploration, hypothesis generation, iterative testing, and self-regulated reasoning, all of which align with FI learners' strengths in autonomous information processing and analytical decomposition (Kozhevnikov et al., 2022). CPS's open-ended phases give FI learners the freedom to restructure problems, evaluate alternative strategies, and persist through cognitive disequilibrium processes that enhance deep problem-solving engagement. Recent studies also show that FI learners excel in problem-based cycles that demand strategic flexibility and metacognitive control, both of which are highly activated in CPS tasks (Ramli et al., 2023).

In contrast, FD students benefit more from PBL because it provides structured collaboration, guided inquiry, and external cues, which reduce cognitive overload and compensate for FD learners' tendency to rely on environmental structure (Zhang & Liu, 2021). The scaffolding and group interactions inherent in PBL offer FD students concrete models of thinking and shared regulation opportunities that support their reasoning processes. A 2023 study by Shaari & Mahmood further confirms that FD learners perform better in learning environments where teacher guidance and peer support are more explicit, enabling them to gradually build understanding before independently solving problems.

The significant interaction found in this study underscores the importance of matching instructional models with students' cognitive profiles. CPS is highly compatible with FI learners, whereas PBL can serve as a more supportive environment for FD learners. This pattern demonstrates that instructional innovation alone is insufficient without considering learner characteristics. Aligning learning models with cognitive styles can enhance students' engagement, reduce cognitive strain, and ultimately improve mathematical problem-solving performance.

In sum, the interaction effect affirms that different learners require different instructional affordances, and it highlights the need for adaptive, cognitively responsive pedagogy. Teachers should therefore design learning experiences that leverage FI students' independence while providing FD students with structured support systems, ensuring both groups can reach their optimal problem-solving potential.

The findings of fourth hyothesis indicate that CPS is more effective than PBL in enhancing students' mathematical reasoning, demonstrating that the structured yet flexible phases of CPS better support the development of logical, analytical, and inferential thinking. This result highlights a distinct contribution of CPS: it explicitly requires learners to engage in problem representation, idea generation, critical evaluation, and solution elaboration, processes that are cognitively aligned with the components of mathematical reasoning such as justification, generalization, and relational understanding (Henningsen & Stein, 2020).

The superiority of CPS over PBL in this domain can be theoretically explained through Vygotskian cognitive principles, particularly scaffolding, the Zone of Proximal Development (ZPD), and socially mediated reasoning. CPS offers highly structured cognitive scaffolds during each stage fact finding, problem definition, idea generation, evaluation, and implementation which guide students progressively from lower-order processing to higher-order reasoning. This structured transition keeps learners operating within their ZPD while continuously pushing them toward more complex reasoning operations (Lantolf & Poehner, 2022). In contrast, PBL is rich in authentic context but

offers less explicit cognitive scaffolding, making it less optimal for students who require guided reasoning pathways (Savery, 2020).

Moreover, CPS supports deliberate metacognitive engagement, particularly during idea evaluation and solution-testing phases, which encourages students to justify their thinking a key indicator of advanced mathematical reasoning. Recent empirical research corroborates this mechanism: structured problem-solving frameworks significantly improve reasoning precision and coherence compared to open inquiry models like PBL (Putra & Retnawati, 2022; Yusof et al., 2023).

Another theoretical explanation is that CPS strengthens reasoning through systematic cognitive conflict. By requiring students to compare multiple ideas and evaluate alternatives, CPS stimulates dissonance that drives deeper logical processing an effect widely recognized in recent cognitive studies (Zhang & Pang, 2021). PBL, although beneficial for conceptual understanding and collaboration, does not always enforce structured comparison of alternative solutions, which limits its ability to cultivate formal reasoning skills.

This study therefore contributes to the literature by demonstrating that CPS not only improves problem-solving performance (Hypothesis 1) but also enhances more complex cognitive competencies such as mathematical reasoning, surpassing PBL in both domains. This dual effect finding represents a meaningful novelty: while many previous studies examined CPS or PBL independently, few directly compared their impact on mathematical reasoning with clear theoretical mechanisms supported by updated empirical evidence. The present study confirms that reasoning development requires not only exploration and collaboration as emphasized in PBL but also explicit cognitive structuring, which is inherently embedded in the CPS model.

Overall, the results show that CPS provides a more deliberate and cognitively aligned pathway for developing mathematical reasoning, offering both theoretical and empirical justification for its use in mathematics classrooms, particularly when the instructional goal is to cultivate higher-order analytical thinking.

The findings of fifth hypothesis show that FI students outperform FD students in mathematical reasoning, confirming that cognitive style plays a significant role in shaping students' ability to justify, generalize, and analyze mathematical relationships. FI learners tend to process information analytically and independently, enabling them to identify relevant structures in mathematical tasks and apply reasoning strategies more effectively than their FD counterparts. This aligns with prior research indicating that FI students exhibit stronger abstraction skills and higher accuracy in inferential thinking (Kozhevnikov et al., 2022).

A key explanation lies in the cognitive autonomy and perceptual differentiation characteristic of FI learners. FI students can separate essential information from distracting details, allowing them to construct internal logic chains and evaluate alternative reasoning paths. These abilities support advanced mathematical reasoning processes such as forming conjectures, constructing proofs, and articulating conceptual justifications skills widely recognized as markers of higher-order reasoning (Henningsen & Stein, 2020). Recent findings reinforce this pattern: FI learners consistently demonstrate stronger performance in tasks requiring analytical decomposition and structural recognition (Ramli et al., 2023).

In contrast, FD students rely more heavily on external cues and environmental structure, which can limit their reasoning performance when tasks require independent inferential processing. FD learners often struggle with problem decontextualization and tend to depend on teacher guidance or peer scaffolds, resulting in slower cognitive restructuring when confronting complex problems (Zhang & Liu, 2021). Studies published after 2021 similarly report that FD students exhibit weaker logical coherence and difficulty sustaining multi-step reasoning without continuous support (Shaari & Mahmood, 2023).

The results also highlight that mathematical reasoning is not merely influenced by instructional strategies (as shown in Hypothesis 4), but also by intrinsic learner characteristics, demonstrating that cognitive style acts as a moderator of reasoning development. This moderating role represents an important scientific contribution: while prior studies have examined FI–FD differences in general cognitive performance, fewer have explicitly linked these differences to formal mathematical reasoning, especially in conjunction with structured learning models such as CPS and PBL. The current findings strengthen the theoretical understanding that reasoning ability emerges from the interaction between cognitive independence and the capacity for analytical restructuring—traits more aligned with the FI profile (Tinajero & Páramo, 2019).

Therefore, this study contributes novel evidence that FI learners possess inherent cognitive advantages for mathematical reasoning due to their analytical orientation, perceptual differentiation, and capacity for self-directed logical exploration. Meanwhile, FD students may require additional scaffolding and guided reasoning strategies to reach comparable levels of performance. These findings reinforce the need for differentiated instructional designs that accommodate cognitive style differences to optimize reasoning development.

The results of sixth hypothesis show a significant interaction between learning strategies (CPS vs. PBL) and cognitive styles (FI vs. FD) in shaping students' mathematical reasoning. This interaction indicates that the effectiveness of an instructional model depends on the cognitive characteristics of learners, and that neither CPS nor PBL is universally superior for all students. Instead, CPS maximizes reasoning performance among FI students, whereas PBL provides comparatively better support for FD students, although FI students still outperform FD students overall. This pattern affirms that reasoning processes emerge from the dynamic relationship between instructional scaffolds and individual cognitive tendencies (Tinajero & Páramo, 2019).

FI students benefit the most from CPS because the model requires self-regulated analysis, hypothesis generation, logical evaluation, and metacognitive monitoring, aligning closely with FI learners' strengths in autonomous and analytical processing. CPS phases particularly idea generation, evaluation, and solution refinement activate the cognitive operations essential for mathematical reasoning, such as justification and generalization. Empirical studies confirm that FI learners show heightened reasoning performance in highly structured reasoning cycles that demand analytical flexibility and independent judgment (Kozhevnikov et al., 2022; Ramli et al., 2023).

Conversely, FD learners demonstrate relatively better reasoning performance under PBL due to its collaborative scaffolding, shared regulation, and contextual cues, which compensate for their reliance on external structure. The social interaction and guided inquiry in PBL help reduce cognitive load and support FD students in articulating reasoning steps they might struggle to construct independently. Recent research provides similar evidence, showing that FD learners display improved conceptual reasoning in group-based, guided problem environments (Zhang & Liu, 2021; Shaari & Mahmood, 2023).

From a theoretical standpoint, the interaction can also be explained through Vygotsky's principles, particularly the Zone of Proximal Development (ZPD) and socially mediated reasoning. For FI students, CPS expands the ZPD by providing cognitive scaffolding without excessive guidance, enabling students to internalize reasoning structures. Meanwhile, PBL supports FD learners' ZPD by offering continuous social scaffolds peer explanation, teacher prompts, and shared modeling that facilitate the gradual internalization of reasoning strategies (Lantolf & Poehner, 2022).

The novelty of this study lies in demonstrating that reasoning development depends not only on instructional design (as shown in Hypothesis 4) or cognitive style alone (as shown in Hypothesis 5), but on the interaction between the two. Few earlier studies have examined how CPS and PBL interact specifically with FI–FD cognitive styles to influence mathematical reasoning, making this combined

analysis a meaningful contribution. The results highlight that reasoning does not emerge uniformly across learners; instead, instructional effectiveness is contingent upon cognitive compatibility between learning models and students' processing tendencies.

Overall, the findings underscore the importance of adaptive pedagogy in mathematics education. Effective reasoning instruction must align structured cognitive scaffolds (as in CPS) with learner independence (as in FI), or collaborative scaffolds (as in PBL) with learner dependence on external cues (as in FD). This reinforces the argument that developing students' mathematical reasoning requires not only high-quality instructional models but also cognitively responsive teaching tailored to diverse learners.

Implications

The findings of this study make significant contributions to the development of mathematics learning theory, particularly in the application of Collaborative Problem Solving (CPS) and Problem-Based Learning (PBL). CPS has been shown to be more effective in enhancing problem-solving and mathematical reasoning abilities, especially for students with a Field-Independent (FI) cognitive style. This supports Vygotsky's sociocultural theory, emphasizing the importance of scaffolding and social interaction in cognitive development. Practically, the results recommend prioritizing CPS for FI learners to optimize analytical and collaborative learning, while PBL should be tailored for Field-Dependent (FD) learners through structured scaffolding. Schools are encouraged to integrate cognitive style profiling into instructional planning to create more personalized and effective mathematics learning environments.

Limitations and Suggestions for Future Research

This study has limitations in terms of generalizability, as it involved students from a single school in Indonesia. Future research should be conducted across various educational contexts and levels to assess the effectiveness of CPS and PBL in enhancing mathematical reasoning. Additionally, further research is needed to explore the mediating mechanisms such as metacognition and collaborative reasoning that may explain why CPS is more effective than PBL. It is also recommended that future studies focus on developing targeted supports for FD learners, such as digital scaffolding tools or more explicit teaching structures, to reduce performance gaps between FD and FI students.

CONCLUSION

This study demonstrates that Collaborative Problem Solving (CPS) is more effective than Problem-Based Learning (PBL) in enhancing both problem-solving and mathematical reasoning abilities. Students with a Field-Independent (FI) cognitive style perform significantly better than those with a Field-Dependent (FD) style. Additionally, there is a significant interaction between learning strategies and cognitive styles, with CPS benefiting FI students more and PBL being more effective for FD learners. These findings highlight the importance of cognitive style profiling in instructional planning to create personalized learning environments. Teachers are encouraged to integrate structured collaboration, particularly CPS, for FI students and use scaffolded PBL strategies for FD learners. This approach ensures more effective learning outcomes in mathematics education.

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AUTHOR CONTRIBUTIONS STATEMENT

AS, INS, CS and HP designed the study and developed the methodology. AS conducted the data collection and analysis. INS, CS and HP supervised the research process. All authors contributed to the manuscript's writing and approved the final version for publication.

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