

Enhancing Students' Metacognitive Knowledge through Problem-Based Learning Integrated with Cognitive Conflict Approach: A Study in Newtonian Physics Education

^{1*} Muhammad Asy'ari, ¹ M. Muhali, ² Cleci T. Werner de Rosa

¹ Mandalika University of Education, Jl. Pemuda No. 59A Mataram, 83125 Indonesia

² Institute of Exact Sciences and Geosciences, University of Passo Fundo, RS, Brazil

*Corresponding Author e-mail: muhammadasyari@undikma.ac.id

Received: July 2022; Revised: July 2024; Published: November 2024

Abstract

This study investigates the effectiveness of a Problem-Based Learning (PBL) model integrated with cognitive conflict strategies in improving students' metacognitive knowledge in physics education. Conducted in an Indonesian senior high school, the study involved three classes implementing different instructional models: PBL with cognitive conflict, PBL alone, and expository teaching. Using a pretest-posttest design, students' declarative, procedural, and conditional metacognitive knowledge was assessed. Descriptive and inferential analyses revealed that all instructional models produced significant learning gains, with the PBL + cognitive conflict model showing the most notable improvements, especially in conditional knowledge ($n\text{-gain} = 0.72$; Cohen's $d = 1.20$). Although ANOVA results were statistically non-significant, effect size analysis confirmed substantial educational impact. The findings highlight the dual role of cognitive conflict and metacognitive scaffolding in fostering self-regulated learning and conceptual understanding. This study supports the integration of metacognitive strategies into inquiry-based instructional models and underscores the cultural compatibility of PBL in Indonesian educational settings.

Keywords: Metacognitive Knowledge; Cognitive Conflict; Problem-Based Learning; Metacognition; Physics Education

How to Cite: Asy'ari, M., Muhali, M., & da Rosa, C. T. W. (2024). Enhancing Students' Metacognitive Knowledge through Problem-Based Learning Integrated with Cognitive Conflict Approach: A Study in Newtonian Physics Education. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, 8(3). 435-452. <https://doi.org/10.36312/e-saintika.v8i3.761>



<https://doi.org/10.36312/e-saintika.v8i3.761>

Copyright© 2024, Asy'ari et al.

This is an open-access article under the [CC-BY-SA](#) License.



INTRODUCTION

Metacognition, defined as the awareness and regulation of one's own cognitive processes, has long been recognized as a crucial determinant of learning effectiveness (Flavell, 1979; McCormick, 2003; Weinert & Kluwe, 1987). It enables students to plan, monitor, and evaluate their thinking strategies, leading to improved academic outcomes. In the context of 21st-century education, metacognition has gained renewed emphasis as a core competency necessary for fostering independent, reflective, and lifelong learners (Goren & Kaya, 2023; Muhali, 2019; National Research Council, 2012). This emphasis is also reflected in Indonesia's national curriculum (Permendikbud No. 69/2013), which mandates the integration of higher-order thinking, including metacognition, into science education at all levels (Anggraena et al., 2022).

However, despite these mandates, metacognitive awareness remains underdeveloped among students, particularly in physics learning where conceptual understanding is essential. Based on teacher interviews at MAN 3 Central Lombok, learning is predominantly conducted through lecture-based methods, emphasizing rote memorization rather than self-directed inquiry. This pedagogical gap limits students' ability to reflect on their understanding, solve problems independently, and adapt their strategies—core components of metacognitive competence.

Numerous studies have documented this issue. For instance, Heswandi et al. (2013) observed that students struggle with internalizing learning strategies such as planning and self-monitoring. Similarly, Adhitama et al. (2018) and Wicaksono (2013) noted that low metacognitive awareness contributes to superficial engagement in problem-solving tasks. Recent evidence corroborates these findings: students with strong metacognitive skills exhibit greater resilience in science learning and outperform their peers in complex reasoning tasks (Alpindo et al., 2024; Balashov et al., 2021).

Problem-Based Learning (PBL) has been promoted as an effective model that fosters metacognitive development to improve these outcomes. PBL encourages students to engage in inquiry, reflect on their thinking, and collaboratively solve real-world problems (Chen, 2024). Recent meta-analyses highlight the consistent benefits of PBL for enhancing metacognitive strategies, especially in science and STEM contexts (Ilahi et al., 2024; Knogler et al., 2022; Shofiyah et al., 2024). In Indonesian settings, Hidayah et al. (2022) and Marthaliakirana et al. (2022) found that students exposed to PBL models demonstrated significant improvements in their ability to self-monitor and regulate learning.

Nevertheless, while PBL provides a conducive environment for developing metacognition, its impact can be further amplified through the integration of cognitive conflict. This approach involves deliberately presenting students with discrepant events or contradictory information, challenging their prior knowledge and triggering conceptual restructuring (Asy'ari & Muhali, 2023). Recent studies confirm that cognitive conflict activates deeper reflection and promotes metacognitive regulation, particularly in science learning where misconceptions are prevalent (Alpindo et al., 2024; Li et al., 2021; Yusnaeni et al., 2020). Moreover, cognitive conflict stimulates diagnostic reasoning and self-regulation, enhancing students' ability to adapt strategies and evaluate evidence (Schnaubert et al., 2021).

Despite the well-established benefits of both Problem-Based Learning (PBL) and cognitive conflict approaches in enhancing student learning, their combined application remains underexplored, particularly in the context of Indonesian secondary physics education. While reflective-metacognitive models have shown promise in improving students' awareness and regulation of learning processes (Muhali et al., 2019), these models typically emphasize self-reflection without explicitly confronting misconceptions that are prevalent in conceptual domains such as Newtonian mechanics. Recent reviews (Ilahi et al., 2024; Karaşah Çakici et al., 2021) indicate a growing interest in instructional designs that integrate metacognitive training into inquiry-based learning, yet studies specifically merging PBL with structured cognitive conflict interventions are still scarce.

Moreover, the operationalization of cognitive conflict within a PBL framework—for example, through discrepant events, structured simulations, or collaborative

prediction-reflection activities—has received limited empirical attention (Cheng, 2023; Li et al., 2021). Studies by Liu et al. (2021) and Charro (2021) highlight the potential of mobile-assisted inquiry tasks and authentic problem scenarios to stimulate cognitive disequilibrium, but rarely are these explored in tandem with metacognitive scaffolds. Alpindo et al. (2024) emphasize that cognitive conflict must be paired with metacognitive prompts (e.g., self-questioning, prediction evaluation) to meaningfully foster conceptual restructuring and self-regulated learning. Without such integration, students may fail to recognize or resolve conflicts in understanding, resulting in superficial engagement.

In the Indonesian context, there is an urgent need to investigate how tools like guided inquiry worksheets, formative feedback loops, and peer-led dialogue can be embedded into PBL activities to generate productive cognitive conflict while supporting metacognitive monitoring. Addressing this intersection offers a promising avenue to enhance both conceptual understanding and metacognitive development in science classrooms—particularly for complex and abstract topics such as Newton's Laws, where misconceptions are persistent and resilient (Knogler et al., 2022; Yusnaeni et al., 2020).

Thus, this study aims to address this gap by examining the effectiveness of a Problem-Based Learning model with a cognitive conflict approach in improving students' metacognitive knowledge on Newton's Laws. This research not only contributes to the limited body of empirical studies on integrative instructional models in Indonesian science education, but also provides practical insights into how metacognitive competence can be cultivated through structured, conflict-rich inquiry learning.

METHOD

Research Design

This study employed a quasi-experimental design, specifically the static-group pretest-posttest design (Fraenkel et al., 2023), which is widely adopted in small-N educational research to assess intervention effectiveness where random assignment at the individual level is not feasible (Hanifha et al., 2023; Subagiyo et al., 2023). This design is appropriate for educational settings where intact class groups are maintained and group-level interventions are applied. The study involved three intact class groups, each receiving different instructional treatments. The structure of the design is illustrated in Figure 1.

Group	Pretest	Treatment	Posttest
XA	O1	PBL with cognitive conflict	O2
XB	O3	PBL only	O4
XC	O5	Expository (control group)	O6

Figure 1. Static-Group Pretest-Posttest Design (Adapted from Fraenkel & Wallen, (2023))

In this model, pretests (O1, O3, O5) were conducted using a validated metacognitive knowledge test and a metacognitive awareness questionnaire. These instruments were designed to establish a baseline of students' existing understanding and regulatory skills before any instructional treatment was applied.

Following the pretests, interventions were implemented according to group assignments. Class XA received instruction using the Problem-Based Learning (PBL) model integrated with a cognitive conflict approach, designed to challenge students' existing conceptions and stimulate reflective thinking. Class XB was taught using a standard PBL model that focused on inquiry and problem-solving without the added element of cognitive conflict. Class XC served as the control group and received traditional expository learning, characterized by teacher-centered instruction and minimal student interaction.

After the interventions, posttests (O2, O4, O6) were administered to all groups. These assessments aimed to measure changes in students' metacognitive knowledge and awareness, allowing the researchers to evaluate the effectiveness of each instructional model.

While this design provides a practical structure for classroom-based research, it has limitations, notably the small total sample size ($N=38$), which may reduce statistical power. Future studies could incorporate power analysis or use repeated measures ANOVA for more robust interaction effect analysis (Abgao, 2023; Rozaq et al., 2023).

Population and Research Sample

The population for this study comprised all tenth-grade students enrolled at MAN 3 Central Lombok during the 2021/2022 academic year. To ensure comprehensive representation, a saturated sampling technique was employed, which involved including the entire student population that met the criteria.

A total of 38 students participated in the study, distributed across three existing classes. Group E1, corresponding to Class XA, consisted of 13 students and received the PBL model with a cognitive conflict approach. Group E2, or Class XB, included 14 students who were taught using the standard PBL model. The control group, labeled as Group K (Class XC), comprised 11 students and followed an expository instructional model. This complete distribution ensured that each instructional approach could be meaningfully evaluated across comparable educational settings.

Group assignment to treatment was determined using cluster random sampling, a valid technique for small-N research contexts where group-level interventions are prioritized (Fiqri et al., 2024; Pramono et al., 2023). This technique ensures natural classroom settings are preserved while minimizing contamination between instructional methods.

Instruments and Procedures

Metacognitive Knowledge Test

To assess students' metacognitive knowledge in the context of Newton's Laws, a validated open-ended test was designed encompassing three key indicators: declarative knowledge, procedural knowledge, and conditional knowledge. These indicators were carefully aligned with Bloom's revised taxonomy, ranging from the understanding level (C2) to the evaluating level (C5), and were contextualized using real-life physics phenomena to enhance relevance and engagement. The instrument comprised six descriptive questions, which were organized into two main categories. The first category, focusing on declarative knowledge (C2–C3), included items 1 to 3 that assessed students' ability to recall and explain Newton's laws through familiar, everyday scenarios. The second category, addressing procedural and conditional

knowledge (C4–C5), comprised items 4 to 6, which evaluated students' ability to apply Newtonian principles and reason through complex problem-solving situations. Each item was evaluated using a scoring rubric with clearly defined maximum scores to ensure consistent and objective assessment. The full structure of the instrument is detailed in Table 1.

Table 1. Structure of Metacognitive Knowledge Test Instrument

No.	Category	Cognitive Level	Indicator	Sample Question	Max Score
1	Declarative Knowledge	C2 Understanding	- Students explain Newton's First Law based on daily experience	A motorbike starts suddenly or stops abruptly – why do we lean backward or forward? (Newton's First Law)	10
2	Declarative Knowledge	C3 - Applying	Students identify Newton's Second Law in contextual cases	A small-mass object accelerates faster under the same force than a heavier one – explain using Newton's Second Law	10
3	Declarative Knowledge	C3 - Applying	Students describe Newton's Third Law using observed action-reaction forces	Explain the mutual force between a hand and a table when pushing it, based on Newton's Third Law	10
4	Procedural and Conditional Knowledge	C4 - Analyzing	Students reason through the correctness of a conceptual statement	Is it true that any force on a stationary object causes it to move? Defend your answer with counterexample	20
5	Procedural and Conditional Knowledge	C5 Evaluating	- Students calculate motion parameters based on Newton's laws	If the combined force on a cart (mass = 250 kg) is 100 N, what is its acceleration?	20
6	Procedural and	C5 Evaluating	- Students analyze net force changes	In a lift accelerating upward, a student's weight changes.	20

No.	Category	Cognitive Level	Indicator	Sample Question	Max Score
	Conditional Knowledge		using Newton's Second Law in non-static conditions	Calculate the lift's acceleration using force difference	

All items in the metacognitive knowledge test were subjected to expert review to ensure their validity and relevance. The validation process, conducted by subject-matter experts in physics education, yielded a mean score of 3.17, indicating that the instrument was categorized as valid in terms of clarity, conceptual accuracy, and alignment with the intended metacognitive indicators. To measure students' initial understanding, the test was administered as a pretest before the instructional interventions began. After the completion of the learning sessions, the same instrument was used for post-testing to evaluate shifts in students' conceptual understanding and their ability to apply metacognitive strategies.

Throughout the learning process, particularly in Class XA where the Problem-Based Learning model was combined with cognitive conflict strategies, students were guided through structured worksheets and inquiry-based discussions. These activities were intentionally designed to expose students to real-world phenomena that challenged their initial conceptions and required reflective analysis—effectively preparing them to engage with the assessment items critically. As a result, the instrument functioned not only as a tool for evaluation but also as a means of reinforcing metacognitive development, supporting students in connecting scientific concepts with contextual reasoning and self-regulated learning processes in physics.

Implementation of Cognitive Conflict Strategy

The cognitive conflict intervention in Class XA was designed by identifying common student misconceptions (e.g., "objects in motion require continuous force to stay in motion") and presenting discrepant events or phenomena to challenge them. For example, students observed a simulation of Newton's first law using PhET virtual experiments, followed by guided inquiry questions prompting students to reflect on inconsistencies between observed outcomes and their prior beliefs (Busyairi et al., 2022; Susilawati et al., 2022). This was reinforced through peer dialogue and structured prediction-reflection tasks (Jeharut et al., 2020; Nisa et al., 2023). To ensure consistency, all lesson phases were delivered using inquiry-based worksheets, incorporating multimedia resources and teacher-guided facilitation, as recommended in cognitive conflict instruction design (Jacalan & Castillo, 2023; Winarso et al., 2023).

Data Analysis

Data in this study were analyzed using both descriptive and inferential statistical methods. Students' metacognitive knowledge scores were first calculated using the formula $(\text{Score Obtained} / \text{Maximum Score}) \times 100$, and then categorized into four levels based on criteria by Ratumanan and Laurens (2011): *Very Good* (≥ 80), *Good* (70–79), *Fair* (60–69), and *Poor* (< 60). To evaluate the magnitude of improvement from pretest to posttest, normalized gain scores (n-gain) were computed following Hake (1998), and classified into three levels: *High* (> 0.7), *Moderate* (0.3–0.7), and *Low* (< 0.3).

Prior to inferential analysis, tests for normality and homogeneity of variance were conducted to determine the appropriate statistical procedures. For data meeting the assumptions of normality, parametric tests such as the paired sample t-test were used to analyze within-group differences. For non-normally distributed data, the Wilcoxon signed-rank test was applied as a non-parametric alternative. To examine between-group differences in students' metacognitive knowledge and awareness, a one-way ANOVA was performed. However, interaction effects were not analyzed due to the limitations of the static-group design.

All statistical analyses were performed using IBM SPSS version 26. Although the ANOVA results indicated no statistically significant differences among groups, educational significance was further explored through the analysis of effect sizes and patterns of within-group gains. This approach allowed for a more nuanced interpretation of learning outcomes beyond p-values alone.

Ethical Statement

This research was conducted in compliance with ethical standards for educational research. Prior to data collection, formal permission was obtained from the head of MAN 3 Central Lombok. Informed consent was secured from all student participants and their guardians. The research procedures ensured voluntary participation, anonymity, and confidentiality of all respondents. No identifiable personal data were collected, and participants were free to withdraw at any stage without consequence. The study was conducted in alignment with the principles outlined in the Declaration of Helsinki for research involving human participants.

RESULTS AND DISCUSSION

Descriptive Analysis of Pretest and Posttest

Students' metacognitive knowledge was assessed through a structured six-item open-ended test focusing on the three core dimensions of metacognition: declarative, procedural, and conditional knowledge, all anchored to Newton's Laws of Motion. This instrument was administered both before and after the instructional interventions across three experimental groups at MAN 3 Central Lombok. Each group experienced a different instructional model: Class XA implemented the PBL model integrated with cognitive conflict, Class XB applied a standard PBL model, and Class XC used conventional expository instruction.

As presented in Table 2, all groups showed measurable improvement in metacognitive knowledge. The conditional knowledge indicator exhibited the highest normalized gain (n-gain) across all groups, suggesting it was most responsive to instructional interventions. Class XA showed the most substantial improvement with an overall average n-gain of 0.608 and a conditional knowledge gain of 0.72. Class XB and Class XC also demonstrated improvements, though slightly lower, with average n-gains of 0.573 and 0.537, respectively. The relatively lower gains in procedural knowledge across all groups highlight a potential need for more explicit instructional strategies targeting procedural application.

These trends support the hypothesis that instruction incorporating cognitive conflict can enhance students' ability to identify, apply, and adapt cognitive strategies, especially when facing conceptually challenging physics content.

Table 2. Mean Pretest, Posttest, and N-Gain Scores by Class and Knowledge Indicator

Class	N	Indicator	Pretest	Posttest	N-Gain
XA	13	Declarative	5.77	8.27	0.59
		Procedural	8.07	10.96	0.24
		Conditional	7.12	16.35	0.72
XB	14	Declarative	5.36	7.86	0.54
		Procedural	7.50	11.96	0.36
		Conditional	7.86	14.82	0.57
XC	11	Declarative	5.91	8.18	0.56
		Procedural	7.73	11.36	0.30
		Conditional	6.82	14.09	0.55

Statistical Test Results

Initial significance testing is summarized in Table 3. Normality was confirmed for Groups XA and XC using the Kolmogorov-Smirnov test, allowing for paired t-tests. Group XB, however, showed non-normal distribution ($p = .003$), and was therefore analyzed with the Wilcoxon signed-rank test. All three groups exhibited statistically significant improvements in metacognitive knowledge. Specifically, Group XA showed a t-value of -3.606 ($p = .004$), Group XB a Z-value of -2.739 ($p = .006$), and Group XC a t-value of -5.590 ($p = .000$). These findings corroborate the gains observed descriptively in Table 2.

Table 3. Results of Normality and Significance Tests for Metacognitive Knowledge Across Classes

Class	Test Used	Normality (p)	Test Statistic	Sig. (p)	Interpretation
XA	Paired t-test	.620	$t = -3.606$	.004	Significant improvement
XB	Wilcoxon Test	.003	$Z = -2.739$	.006	Significant improvement
XC	Paired t-test	.279	$t = -5.590$	.000	Significant improvement

To evaluate differences among the instructional models, a one-way ANOVA was conducted (see Table 4). The analysis yielded no statistically significant difference among the groups ($F(2,35) = 0.759$, $p = .476$), suggesting that, on average, the improvements did not differ significantly across instructional types. This finding aligns with existing literature on the limitations of ANOVA in small-N educational studies, which often lack the statistical power to detect between-group effects despite evident within-group improvements (Dolo et al., 2022; Sanjerehei, 2021).

Table 4. One-Way ANOVA Results for Posttest Metacognitive Knowledge Scores

Source	Sum of Squares	df	Mean Square	F	p
Between Groups	113.107	2	56.553	0.759	0.476
Within Groups	2608.367	35	74.525		
Total	2721.474	37			

Recognizing the limitations of significance testing alone, effect sizes were computed using Cohen's d , as shown in Table 5. These indicate large effects across all groups, with the highest observed in Class XA ($d = 1.20$). The values suggest that even though ANOVA results were not significant, the instructional interventions had considerable educational impact. This supports recommendations in the literature to report both statistical and practical significance (Boscardin et al., 2024; Štemberger, 2021).

Table 5. Effect Size (Cohen's d) of Pretest-Posttest Gains in Metacognitive Knowledge by Class

Class	Instructional Model	Effect Size (Cohen's d)	Magnitude
XA	PBL + Cognitive Conflict	1.20	Large
XB	PBL only	1.08	Large
XC	Expository	1.09	Large

Visual comparisons (Figure 2), further confirmed Group XA's consistent and substantial performance gains. These patterns provide empirical support for the superiority of cognitive conflict-integrated PBL in fostering metacognitive development, consistent with findings by Li et al. (2021) and Alpindo et al. (2024).

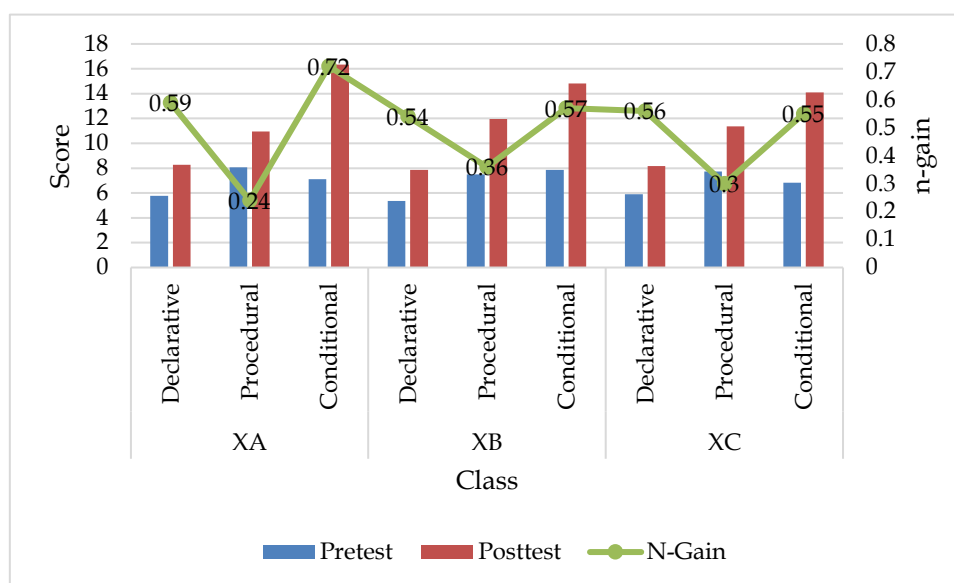


Figure 2. Descriptive comparison of each class

Discussion

Knowledge Dimensions Enhanced by PBL

The results of this study confirm the effectiveness of the Problem-Based Learning (PBL) model, particularly when integrated with cognitive conflict strategies, in enhancing students' metacognitive knowledge. The quantitative data presented in Table 2 provides clear evidence of this enhancement across all three dimensions of metacognitive knowledge: declarative, procedural, and conditional. This finding supports a broader body of literature that identifies PBL as a valuable pedagogical framework for promoting comprehensive cognitive development through real-world problem-solving tasks (Shi & Li, 2024; Wondie et al., 2020).

Declarative knowledge, representing factual and conceptual understanding, improved across all instructional models, with Class XA (PBL + cognitive conflict) achieving a mean n-gain of 0.59, Class XB (PBL only) reaching 0.54, and Class XC (expository) at 0.56. These results demonstrate the capacity of PBL to support knowledge integration and retention, aligning with findings by Shi and Li (2024), who observed that active engagement with content-rich scenarios reinforces declarative understanding.

In terms of procedural knowledge, which relates to the application of methods, Class XB recorded the highest n-gain (0.36), closely followed by Class XC (0.30), and Class XA (0.24). These moderate gains suggest that while all models provided some scaffolding for procedural application, students in PBL environments were more effectively encouraged to manage and execute their own learning strategies. This observation is consistent with Wondie et al. (2020), who emphasize that procedural knowledge in PBL environments is developed through iterative practice, peer collaboration, and self-monitoring.

The most remarkable gains were found in conditional knowledge. Class XA achieved the highest n-gain score of 0.72, compared to 0.57 in Class XB and 0.55 in Class XC, as shown in Table 2. This indicates that students in cognitive-conflict-enriched PBL settings developed a stronger ability to assess when and why to apply specific strategies. These findings echo the work of Nurjanah and Nurbatra (2023), who argue that real-world scenarios presented in PBL stimulate contextual learning and adaptive expertise—critical elements of conditional knowledge development. This finding supports the broader body of literature that identifies PBL as a valuable pedagogical framework for fostering declarative, procedural, and conditional knowledge through real-world problem-solving (Hsbollah & Hassan, 2022; Moscardini et al., 2024; Quinapallo-Quintana & Baldeón-Zambrano, 2024).

Declarative knowledge, which encompasses factual and conceptual understanding, saw meaningful gains across all instructional models, particularly in the PBL and PBL with cognitive conflict groups. The structured inquiry and scenario-based challenges presented in PBL settings provided students with multiple opportunities to assimilate and integrate new knowledge effectively. This aligns with the findings of Shi and Li (2024), who observed that PBL fosters the consolidation of conceptual understanding through engagement in content-rich tasks.

Procedural knowledge, involving the application of methods and strategies, improved moderately in all groups. Gains were more pronounced in PBL contexts where students were encouraged to direct their own learning. As Wondie et al. (2020) suggest, this component of PBL facilitates planning, organization, and evaluation of learning pathways, which strengthens procedural fluency.

The greatest improvements were observed in conditional knowledge, particularly in the PBL with cognitive conflict group. Conditional knowledge entails understanding when and why to apply specific strategies. PBL grounded in real-world scenarios fosters this contextualized learning, and cognitive conflict compels students to reassess prior knowledge and adapt accordingly (Nurjanah & Nurbatra, 2023).

Cognitive Conflict as a Catalyst for Metacognitive Reflection

Beyond enhancing content knowledge, the inclusion of cognitive conflict strategies was pivotal in stimulating metacognitive reflection among students. This was especially evident in Class XA, where students demonstrated the highest gains in conditional knowledge ($n\text{-gain} = 0.72$), as indicated in Table 2. The conditional knowledge dimension requires learners to evaluate when and why to apply certain strategies—cognitive tasks that inherently demand a high level of metacognitive awareness.

By confronting contradictory or unfamiliar information during instructional sessions, students in Class XA were compelled to critically evaluate their assumptions and reconfigure their cognitive frameworks. This iterative cognitive process aligns with findings by Winarso et al. (2023), who emphasized that cognitive conflict, when embedded in multimedia or interactive instruction, effectively resolves misconceptions and promotes metacognitive growth.

In addition, the mediating role of metacognitive awareness—as described by Calleja and Formosa (2020)—was crucial in enabling students to regulate and adjust their understanding when faced with cognitive dissonance. This was corroborated by the statistically significant improvement in Group XA's performance ($p = .004$; see Table 3.2), suggesting that structured cognitive conflict not only initiated critical thinking but also sustained it through reflective monitoring. As Li et al. (2021) point out, such scaffolding mechanisms can lead to more profound learning outcomes. Thus, the integration of cognitive conflict and metacognitive awareness in the PBL setting served as a dynamic scaffolding framework that enriched students' conceptual understanding and strategic learning capabilities.

Contextual Insights from Indonesian Classrooms

This study also provides insights relevant to the Indonesian educational context by highlighting how culturally responsive instructional models like PBL support metacognitive development in secondary classrooms. The consistent improvements observed in all three groups—particularly in declarative and conditional knowledge (as shown in Table 2)—demonstrate that PBL approaches align well with Indonesian students' collaborative learning tendencies. Specifically, students in Class XA and XB, who engaged in group-based problem solving, exhibited strong engagement and learning gains, reflecting the compatibility of PBL with collectivist educational values commonly observed in Indonesia (Hidayah et al., 2022; Marantika, 2021).

Furthermore, students' active participation in discussions and their ability to navigate group dynamics to resolve cognitive conflicts indicate that the PBL framework facilitated not just cognitive but also social learning processes. This reinforces the importance of cultural congruence in instructional design. However, findings by Tsamago and Bayaga (2023) remind educators that successful implementation of metacognitive scaffolding should not overlook local cultural and pedagogical norms. Tailoring scaffolds to fit cultural contexts can enhance the relevance, acceptability, and effectiveness of PBL interventions, especially when aiming to foster deeper cognitive and reflective learning outcomes.

Evaluating Practical Significance

Effect size analysis confirmed the substantial educational impact of the instructional models, as presented in Table 5. The cognitive conflict-enhanced PBL

(Class XA) demonstrated the strongest effect size (Cohen's $d = 1.20$), indicating a large and meaningful impact. This was followed by Class XB ($d = 1.08$) and Class XC ($d = 1.09$), both of which also fell into the large effect category. These results underscore that even in the absence of statistically significant differences reported by the ANOVA ($p = .476$; see Table 4), the interventions produced substantial practical benefits (Boscardin et al., 2024). Such findings highlight the critical need to distinguish between statistical and practical significance, particularly in small-N educational research where sample size limitations may obscure meaningful instructional effects. Furthermore, visual gain charts provided additional confirmation of these patterns, showcasing Group XA's consistent and substantial performance improvements across all metacognitive indicators (Figure 2). These visualizations complement the numerical findings by offering intuitive, accessible representations of learning gains.

Implications for Instructional Design

These results underscore the importance of integrating metacognitive and cognitive scaffolding within inquiry-based learning environments, particularly through PBL models enhanced with cognitive conflict. Data from Table 2 and Table 5 demonstrate how students in Class XA achieved the highest gains in conditional knowledge ($n\text{-gain} = 0.72$) and the largest effect size (Cohen's $d = 1.20$), showcasing the practical impact of this dual scaffolding approach. These findings affirm the assertions by Hung and Tsai (2020) and Tegeh et al. (2021) that metacognitive scaffolding fosters inquiry skills and sustained engagement in science learning contexts.

Furthermore, the structured confrontation of conceptual inconsistencies via cognitive conflict appears to function as an accelerant for self-regulated learning behaviors. It prompted students to evaluate their own understanding and adapt their cognitive strategies in real time, contributing to long-term metacognitive growth. As reflected in the statistically significant gains ($p = .004$; Table 3), the instructional design effectively engaged students in deeper reflection and strategy refinement.

The synergy between cognitive conflict and metacognitive awareness in PBL settings facilitates not only robust cognitive development but also the cultivation of transferable 21st-century competencies. These include self-regulation, adaptability, and critical thinking—skills increasingly essential for learners to thrive in dynamic, complex educational and professional environments.

CONCLUSION

This study provides compelling evidence that the integration of Problem-Based Learning (PBL) and cognitive conflict strategies is effective in enhancing students' metacognitive knowledge across declarative, procedural, and conditional domains. Among the three instructional models tested—PBL with cognitive conflict, PBL alone, and traditional expository teaching—the PBL approach enriched with cognitive conflict yielded the most substantial and consistent improvements. Notably, students in the PBL with cognitive conflict group (Class XA) achieved the highest gains in conditional knowledge ($n\text{-gain} = 0.72$) and demonstrated the strongest effect size (Cohen's $d = 1.20$), emphasizing the model's potential to foster adaptive learning and reflective thinking.

The findings also underscore the synergistic function of cognitive conflict and metacognitive awareness in promoting deeper conceptual understanding. Cognitive

conflict prompted students to reassess and reconstruct their knowledge frameworks, while metacognitive awareness facilitated self-regulation and strategic thinking throughout the learning process. These mechanisms were especially effective in inquiry-based environments like PBL, which naturally accommodate reflection, collaboration, and real-world problem solving.

Furthermore, the culturally responsive design of the PBL model proved to be well-suited to the Indonesian classroom context. Students showed active engagement and collaborative learning behaviors, reinforcing the model's relevance and applicability. Despite the small sample size limiting the statistical generalizability, the large effect sizes observed suggest strong practical implications for broader educational implementation.

RECOMMENDATION

To strengthen instructional practices, educators are encouraged to adopt PBL models that integrate cognitive conflict strategies to enhance students' metacognitive development, particularly in science education. Curriculum design should incorporate authentic problems and structured dissonance activities to foster critical and reflective thinking. It is equally important that teacher preparation programs emphasize culturally responsive, inquiry-based methodologies that support diverse learners. Future studies should explore the long-term effectiveness and broader applicability of this integrated model across varied disciplines and educational contexts. These efforts collectively aim to promote deeper learning and equip students with the cognitive tools necessary for 21st-century challenges. Among the three instructional models tested – PBL with cognitive conflict, PBL alone, and traditional expository teaching – the PBL approach enriched with cognitive conflict yielded the most substantial and consistent improvements. Notably, students in the PBL with cognitive conflict group (Class XA) achieved the highest gains in conditional knowledge ($n\text{-gain} = 0.72$) and demonstrated the strongest effect size (Cohen's $d = 1.20$), emphasizing the model's potential to foster adaptive learning and reflective thinking.

The findings also underscore the synergistic function of cognitive conflict and metacognitive awareness in promoting deeper conceptual understanding. Cognitive conflict prompted students to reassess and reconstruct their knowledge frameworks, while metacognitive awareness facilitated self-regulation and strategic thinking throughout the learning process. These mechanisms were especially effective in inquiry-based environments like PBL, which naturally accommodate reflection, collaboration, and real-world problem solving.

Furthermore, the culturally responsive design of the PBL model proved to be well-suited to the Indonesian classroom context. Students showed active engagement and collaborative learning behaviors, reinforcing the model's relevance and applicability. Despite the small sample size limiting the statistical generalizability, the large effect sizes observed suggest strong practical implications for broader educational implementation.

This study contributes to the growing body of research advocating for active, inquiry-based, and cognitively engaging instructional practices. It provides a replicable model for enhancing metacognitive knowledge and offers actionable

insights for educators, curriculum developers, and policymakers aiming to foster critical and reflective learners equipped for the complexities of the 21st century.

Funding

This research received no external funding.

Acknowledgment

The author thanks the participants who took part in the research study.

Conflict of interests

The authors declare no conflict of interest.

REFERENCES

- Abgao, J. M. (2023). The Effectiveness of Using Graphics Interchange Format (GIF) in Teaching Chemistry. *IJCER (International Journal of Chemistry Education Research)*, 105–112. <https://doi.org/10.20885/ijcer.vol7.iss2.art11>
- Adhitama, R. S., Kusnadi, K., & Supriatno, B. (2018). Kesadaran Metakognitif Siswa dalam Pembelajaran Berbasis Proyek pada Pokok Bahasan Pencemaran Lingkungan. *Assimilation: Indonesian Journal of Biology Education*, 1(1), Article 1. <https://doi.org/10.17509/aijbe.v1i1.11455>
- Alpindo, O., Istiyono, E., & Widiastuti, W. (2024). How Extensively Do Teachers Train Students' Metacognition Abilities in Physics Learning in High School? *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, 10(1), 27–38. <https://doi.org/10.21009/1.10103>
- Anggraena, Y., Ginanto, D., Felicia, N., Andiarti, A., Herutami Indriyanti, H., Alhapip, L., & Setiyowati, D. (with Chatarina, M., Kadariyah, N., Baharudin, B., Ghazali, F., Anggraeni, A., Maisura, R., Arsiah, Z., Waluyo, W., Nurani, D., Wismayanti, E., Tristiani, A., Mulyati, P., Fadhillah, A., Srihayati, T., Pasingga, S., P, F. E., & Pratiwi, S.). (2022). *Panduan pembelajaran dan asesmen kurikulum 2013: Pendidikan anak usia dini, pendidikan dasar, dan menengah*. Pusat Kurikulum dan Pembelajaran. https://pustaka-sma.kemdikbud.go.id:4353/index.php?p=fstream&fid=157&bid=144#flipbook-pdf_collections/1/
- Asy'ari, M., & Muhali, M. (2023). Integrating Inquiry-Based Learning and Cognitive Conflict Strategies to Enhance Critical Thinking in Undergraduate Physics Education. *Multi Discere Journal*, 2(2), 107–124. <https://doi.org/10.36312/mj.v2i2.2722>
- Balashov, E., Pasichnyk, I., & Kalamazh, R. (2021). Metacognitive Awareness and Academic Self-Regulation of HEI Students. *International Journal of Cognitive Research in Science, Engineering and Education*, 10(2), Article 2. <https://doi.org/10.23947/2334-8496-2021-9-2-161-172>
- Boscardin, C. K., Sewell, J. L., Tolsgaard, M. G., & Pusic, M. V. (2024). How to Use and Report on p-values. *Perspectives on Medical Education*, 13(1). <https://doi.org/10.5334/pme.1324>
- Busyairi, A., Makhrus, M., & Verawati, N. N. S. P. (2022). The Effect of Cognitive Conflict Strategy on Improving Understanding of Students' Physics Concepts Reviewing from Cognitive Style. *Jurnal Ilmiah Profesi Pendidikan*, 7(2c), 980–986. <https://doi.org/10.29303/jipp.v7i2c.583>

- Calleja, J., & Formosa, L. (2020). Teacher change through cognitive conflicts: The case of an art lesson study. *International Journal for Lesson & Learning Studies*, 9(4), 383–395. <https://doi.org/10.1108/IJLLS-05-2020-0028>
- Charro, E. (2021). A curricular Delphi study to improve the science education of secondary school students in Spain. *Journal of Research in Science Teaching*, 58(2), 282–304. <https://doi.org/10.1002/tea.21655>
- Chen, R. (2024). Exploring the Effectiveness of Problem-Based Learning as a Constructivist Approach in Enhancing Critical Thinking Skills in High School Classes. *Research and Advances in Education*, 3(4), 26–32. <https://doi.org/10.56397/RAE.2024.04.05>
- Cheng, X. (2023). Flipped Learning Model: An Effective Approach to Primary School STEM Education. *Science Insights Education Frontiers*, 15(1), 2145–2146. <https://doi.org/10.15354/sief.23.co044>
- Dolo, K., Grgantov, Z., & Jelaska, I. (2022). Testing dynamic balance in youth female volleyball players: Development, reliability and usefulness. *Human Movement*, 24(3), 78–84. <https://doi.org/10.5114/hm.2023.116635>
- Fiqri, M. A., Hadiyanto, H., Taufiq, M. A., Irsyad, I., & Putri, R. E. (2024). Contribution of Principal Leadership and School Climate to the Performance of Junior High School Teachers in Padang City. *AL-ISHLAH: Jurnal Pendidikan*, 16(2), Article 2. <https://doi.org/10.35445/alishlah.v16i2.1987>
- Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, 34(10), 906–911. <https://doi.org/10.1037/0003-066X.34.10.906>
- Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2023). *How to design and evaluate research in education* (Eleventh edition). McGraw Hill LLC.
- Goren, D., & Kaya, E. (2023). How is Students' Understanding of Nature of Science Related with Their Metacognitive Awareness? *Science & Education*, 32(5), 1471–1496. <https://doi.org/10.1007/s11191-022-00381-9>
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74. <https://doi.org/10.1119/1.18809>
- Hanifha, S., Erna, M., Noer, A. M., & Talib, C. A. (2023). Scientific Literacy and Environmental Awareness through Undergraduate Student Worksheets Based on Socioscientific Issues. *Jurnal Pendidikan IPA Indonesia*, 12(4), 504–513. <https://doi.org/10.15294/jpii.v12i4.45817>
- Hidayah, R., Fajaroh, F., Parlan, P., & Dasna, I. W. (2022). Collaborative Problem Based Learning to Improve Metacognitive of Chemistry Students: Systematic Literature Review. *AL-ISHLAH: Jurnal Pendidikan*, 14(4), Article 4. <https://doi.org/10.35445/alishlah.v14i4.1172>
- Hsbollah, H. M., & Hassan, H. (2022). Creating Meaningful Learning Experiences with Active, Fun, and Technology Elements in the Problem-Based Learning Approach and Its Implications. *Malaysian Journal of Learning and Instruction*, 19(1), Article 1. <https://doi.org/10.32890/mjli2022.19.1.6>
- Hung, J.-F., & Tsai, C.-Y. (2020). The Effects of a Virtual Laboratory and Meta-Cognitive Scaffolding on Students' Data Modeling Competences. *Journal of*

- Baltic Science Education*, 19(6), 923–939. <https://doi.org/10.33225/jbse/20.19.923>
- Ilahi, D. P., Festiyed, F., Yerimadesi, Yulkifli, Y., Utami, L., & Ratih, A. (2024). Evaluating the Impact of Problem Based Learning on Student's Metacognition in Science Learning: A Meta-Analysis Review. *Jurnal Penelitian Pendidikan Ipa*, 10(8), 526–535. <https://doi.org/10.29303/jppipa.v10i8.7892>
- Jacalan, L. T., & Castillo, A. A. (2023). Effect of Inquiry-based learning approach on the students' performance in Physics. *International Journal of Science and Management Studies (IJSMS)*, 230–233. <https://doi.org/10.51386/25815946/ijsms-v6i3p121>
- Jeharut, R. R. K., Subandi, S., & Habiddin, H. (2020). Learning Cycle-6e and Cognitive Conflict Strategies: The Remedial Learning to Overcome Misconceptions. *Jurnal Ilmu Pendidikan*, 26(1), Article 1. <https://doi.org/10.17977/um048v26i1p29-38>
- Karaşah Çakici, Ş., Kol, Ö., & Yaman, S. (2021). The Effects of STEM Education on Students' Academic Achievement In Science Courses: A Meta-Analysis. *Kuramsal Eğitim Bilim*, 14(2), 264–290. <https://doi.org/10.30831/akueg.810989>
- Knogler, M., Hetmanek, A., & Seidel, T. (2022). Determining an Evidence Base for Particular Fields of Educational Practice: A Systematic Review of Meta-Analyses on Effective Mathematics and Science Teaching. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.873995>
- Li, X., Chen, G., & Yang, C. (2021). How cognitive conflict affects judgments of learning: Evaluating the contributions of processing fluency and metamemory beliefs. *Memory & Cognition*, 49(5), 912–922. <https://doi.org/10.3758/s13421-021-01143-8>
- Liu, C., Zowghi, D., Kearney, M., & Bano, M. (2021). Inquiry-based mobile learning in secondary school science education: A systematic review. *Journal of Computer Assisted Learning*, 37(1), 1–23. <https://doi.org/10.1111/jcal.12505>
- Marantika, J. E. R. (2021). Metacognitive ability and autonomous learning strategy in improving learning outcomes. *Journal of Education and Learning (EduLearn)*, 15(1), Article 1. <https://doi.org/10.11591/edulearn.v15i1.17392>
- Marthaliakirana, A. D., Suwono, H., Saefi, M., & Gofur, A. (2022). Problem-based learning with metacognitive prompts for enhancing argumentation and critical thinking of secondary school students. *Eurasia Journal of Mathematics, Science and Technology Education*, 18(9), em2148. <https://doi.org/10.29333/ejmste/12304>
- McCormick, C. B. (2003). Metacognition and learning. In *Handbook of psychology: Educational psychology*, Vol. 7. (pp. 79–102). John Wiley & Sons, Inc. <https://doi.org/10.1002/0471264385.wei0705>
- Moscardini, L., Cameron, M., Clark, C., McNeil, N. S. G., Mitchell, C., Nys, D., & Jaap, A. (2024). Our Café Nero sessions: Supporting student teachers to develop their understanding of inclusive practice through problem-based learning. *Support for Learning*, 39(2), 85–90. <https://doi.org/10.1111/1467-9604.12475>
- Muhali, M. (2019). Pembelajaran Inovatif Abad Ke-21. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, 3(2), 25. <https://doi.org/10.36312/e-saintika.v3i2.126>

- Muhali, M., Yuanita, L., & Ibrahim, M. (2019). The Validity and Effectiveness of the Reflective-Metacognitive Learning Model to Improve Students' Metacognition Ability in Indonesia. *Malaysian Journal of Learning and Instruction*, 16. <https://doi.org/10.32890/mjli2019.16.2.2>
- National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (p. 13165). National Academies Press. <https://doi.org/10.17226/13165>
- Nisa, N. Z., Mudrikah, I., Putri, S. J., Prahani, B. K., & Uulaa, R. F. R. (2023). Analyse Implementation of Inquiry-Based Learning in Physics for Learning Outcomes and Thinking Skills. *International Journal of Emerging Research and Review*, 1(3), Article 3. <https://doi.org/10.56707/ijoerar.v1i3.27>
- Nurjanah, L., & Nurbatra, L. H. (2023). The Power of PBL and TPACK: Catalysts for Elevating Students' Writing Learning Outcomes. *Jo-ELT (Journal of English Language Teaching) Fakultas Pendidikan Bahasa & Seni Prodi Pendidikan Bahasa Inggris IKIP*, 10(2), 157-166. <https://doi.org/10.33394/jo-elt.v10i2.8043>
- Pramono, H., Nurafiaty, S., Rahayu, T., & Sugiharto, S. (2023). The influence of physical education teacher performance on elementary students' character building. *Jurnal Cakrawala Pendidikan*, 42(1), Article 1. <https://doi.org/10.21831/cp.v42i1.53359>
- Quinapallo-Quintana, A. M., & Baldeón-Zambrano, A. X. (2024). Project-based learning. *International Research Journal of Management, IT and Social Sciences*, 11(1), Article 1. <https://doi.org/10.21744/irjmis.v11n1.2415>
- Ratumanan, T. G., & Laurens, T. (2011). *Penilaian Hasil Belajar pada Tingkat Satuan Pendidikan*. Unesa University Press.
- Rozaq, A. B., Wardiah, D., & Manullang, J. G. (2023). Improving Students' Understanding in Practicing Static and Dynamic Gymnastic Movements through Audio Visual. *Journal of Social Work and Science Education*, 4(3), 76-82. <https://doi.org/10.52690/jswse.v4i3.515>
- Sanjerehei, M. M. (2021). Sample Size Calculations for Vegetation Studies. *Macedonian Journal of Ecology and Environment*, 23(2), 85-97. <https://doi.org/10.59194/MJEE21232085ms>
- Schnaubert, L., Krukowski, S., & Bodemer, D. (2021). Assumptions and confidence of others: The impact of socio-cognitive information on metacognitive self-regulation. *Metacognition and Learning*, 16(3), 855-887. <https://doi.org/10.1007/s11409-021-09269-5>
- Shi, Y., & Li, W. (2024). Empowering Education: Unraveling the Factors and Paths to Enhance Project-Based Learning Among Chinese College Students. *Sage Open*, 14(3), 21582440241276600. <https://doi.org/10.1177/21582440241276600>
- Shofiyah, A., Suprianto, Vajari, R., & Robiz, M. N. Z. (2024). Meta-analisis Kemampuan Kognitif Siswa dalam Pembelajaran Fisika dengan Model Problem Based Learning (PBL). *Mutiara: Jurnal Ilmiah Multidisiplin Indonesia*, 2(3), Article 3. <https://doi.org/10.61404/jimi.v2i3.264>
- Štemberger, T. (2021). Statistical Significance and/or Effect Size? *Journal of Elementary Education*, 14(4), Article 4. <https://doi.org/10.18690/rei.14.4.485-500.2021>
- Subagiyo, L., Riani, S. A., & Hakim, A. (2023). Exploring Students' Critical Thinking Skills with A Problem-based Learning Model Assisted by Animated Video in

- Static Fluid Learning. *Berkala Ilmiah Pendidikan Fisika*, 11(2), 218.
<https://doi.org/10.20527/bipf.v11i2.15815>
- Susilawati, S., Doyan, A., Mulyadi, L., Abo, C. P., & Pineda, C. I. S. (2022). The Effectiveness of Modern Physics Learning Tools Using the PhET Virtual Media Assisted Inquiry Model in Improving Cognitive Learning Outcomes, Science Process Skills, and Scientific Creativity of Prospective Teacher Students. *Jurnal Penelitian Pendidikan IPA*, 8(1), Article 1.
<https://doi.org/10.29303/jppipa.v8i1.1304>
- Tegeh, I. M., Astawan, I. G., Sudiana, I. K., & Kristiantari, M. G. R. (2021). Murder Learning Model Assisted by Metacognitive Scaffolding to Improve Students' Scientific Literacy and Numeracy Skills through Science Studies in Elementary Schools. *Jurnal Pendidikan IPA Indonesia*, 10(4), Article 4.
<https://doi.org/10.15294/jpii.v10i4.32926>
- Tsamago, H., & Bayaga, A. (2023). Self-organized learning environments (SOLEs) pedagogy as a conduit to learners' metacognitive skills and conceptual understanding of "S" in STEM: The South African study. *European Journal of Science and Mathematics Education*, 11(3), 533–555.
<https://doi.org/10.30935/scimath/13038>
- Weinert, F. E., & Kluwe, R. (Eds.). (1987). *Metacognition, motivation, and understanding*. L. Erlbaum Associates.
- Wicaksono, B. (2013). Peningkatan Kemampuan Metakognitif Fisika Melalui Model Pembelajaran Problem Based Learning Pada SMK Pancasila 1 Kutoarjo. *Radiasi : Jurnal Berkala Pendidikan Fisika*, 3(2), Article 2.
- Winarso, W., Toheri, & Udin, T. (2023). Addressing the Challenge of Mathematical Misconceptions: Development of Interactive Multimedia Based on Cognitive Conflict Strategy. *Journal of Education Technology*, 7(3), Article 3.
<https://doi.org/10.23887/jet.v7i3.63037>
- Wondie, A., Yigzaw, T., & Worku, S. (2020). Effectiveness and Key Success Factors for Implementation of Problem-Based Learning in Debre Tabor University: A Mixed Methods Study. *Ethiopian Journal of Health Sciences*, 30(5).
<https://doi.org/10.4314/ejhs.v30i5.21>
- Yusnaeni, Y., Corebima, A. D., Susilo, H., & Zubaidah, S. (2020). The Contribution of Metacognitive Skills and Creative Thinking Skills in 21st Century Learning. *Universal Journal of Educational Research*, 8(4A), 31–36.
<https://doi.org/10.13189/ujer.2020.081805>