PLUSMINUS
Jurnal Pendidikan Matematika

Developing a PBL–Flipped Classroom Model Based on Baduy Local Wisdom to Enhance Students' Mathematical Critical Thinking

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ABSTRAK

Penelitian ini dilatarbelakangi oleh rendahnya kemampuan berpikir kritis matematis siswa Indonesia, khususnya dalam menyelesaikan masalah non-rutin. Penelitian ini bertujuan untuk mengembangkan dan menguji efektivitas model Problem Based Learning – Flipped Classroom (PBL-FC) yang terintegrasi dengan kearifan lokal Baduy dalam meningkatkan kemampuan berpikir kritis matematis siswa. Desain penelitian menggunakan pendekatan Research & Development (R&D) dengan kerangka ASSURE untuk pengembangan model, serta desain quasi-eksperimen dengan kelompok kontrol pretest – posttest untuk menguji efektivitasnya. Penelitian melibatkan 60 siswa kelas lima SD Negeri Alaswangi 1, Lebak-Banten, yang dipilih berdasarkan kesiapan, motivasi, dan akses terhadap sumber belajar. Instrumen penelitian meliputi tes berpikir kritis matematis, lembar observasi pelaksanaan pembelajaran, serta kuesioner respons guru dan siswa. Data dianalisis menggunakan uji validitas dan reliabilitas, ANOVA, uji lanjut (post hoc), dan N-Gain. Hasil penelitian menunjukkan validasi ahli terhadap model sebesar 87,5% (sangat valid), keterlaksanaan pembelajaran 97,08% (sangat praktis), serta respons guru dan siswa masing-masing 91,67% dan 86,16% (baik hingga sangat baik). Peningkatan rata-rata kemampuan berpikir kritis matematis siswa lebih tinggi pada kelompok PBL-FC (73,91%) dibandingkan dengan kelompok PBL konvensional (56,83%). Hasil ANOVA menunjukkan efek signifikan dari kemampuan akademik ($F=17,536$; $p<0,001$), model pembelajaran ($F=5,100$; $p<0,001$), dan interaksi keduanya ($F=2,100$; $p<0,001$). Uji lanjut menegaskan adanya perbedaan signifikan antar kelompok kemampuan tinggi – sedang (9,76), tinggi – rendah (19,83), dan sedang – rendah (10,06) dengan $p\leq0,002$. Kesimpulannya, model PBL-FC berbasis

ABSTRACT

This research is motivated by the low mathematical critical thinking skills of Indonesian students, especially in solving non-routine problems. This study aims to develop and test the effectiveness of the Problem Based Learning – Flipped Classroom (PBL-FC) model integrated with Baduy local wisdom in improving students' mathematical critical thinking skills. The research design uses a Research & Development (R&D) approach with the ASSURE framework for model development, as well as a quasi-experimental design with a pretest – posttest control group to test its effectiveness. The study involved 60 fifth-grade students of Alaswangi 1 Elementary School, Lebak-Banten, who were selected based on their readiness, motivation, and access to learning resources. The research instruments included a mathematical critical thinking test, observation sheets for learning implementation, and teacher and student response questionnaires. Data were analyzed using validity and reliability tests, ANOVA, post hoc tests, and N-Gain. The results showed expert validation of the model at 87.5% (very valid), learning implementation at 97.08% (very practical), and teacher and student responses at 91.67% and 86.16% (good to very good), respectively. The average increase in students' mathematical critical thinking skills was higher in the PBL-FC group (73.91%) compared to the conventional PBL group (56.83%). ANOVA results showed significant effects of academic ability ($F=17.536$; $p<0.001$), learning model ($F=5.100$; $p<0.001$), and the interaction between the two ($F=2.100$; $p<0.001$). Further tests confirmed significant differences between the high-medium ability groups (9.76), high-low (19.83), and medium-low (10.06) with $p\leq0.002$. In conclusion, the PBL-FC model based on Baduy local wisdom is effective, valid, and practical to be implemented in the Independent Curriculum, especially in improving students' mathematical critical thinking skills.

DOI: https://doi.org/10.31980/plusminus.v5i3.3240

kearifan lokal Baduy efektif, valid, dan praktis untuk diterapkan dalam Kurikulum Merdeka, khususnya dalam meningkatkan kemampuan berpikir kritis matematis siswa.

Kata Kunci: ASSURE; Flipped Classroom; Kearifan Lokal Baduy; Kemampuan Berpikir Kritis Matematis; Problem-Based Learning,

Keywords: ASSURE; Flipped Classroom; Baduy Local Wisdom; Mathematical Critical Thinking; Problem-Based Learning.

Article Information:

Accepted Article: 20 August 2025, Revised: 22 October 2025, Published: 30 November 2025

How to Cite:

Fariji, I., Ardianto, T., Kusmana, N., Subekhi, A. I., & Junaedi, Y. (2025). Developing a PBL – Flipped Classroom Model Based on Baduy Local Wisdom to Enhance Students' Mathematical Critical Thinking. *Plusminus: Jurnal Pendidikan Matematika, 5*(3), 465-494.

1. INTRODUCTION

The twenty-first century demands mastery of critical thinking (Noverli, Nery, & Hadi, 2025), a higher-order cognitive skill essential for academic achievement (Vrasetya & Nasution, 2024), problem-solving (Indrajaya et al., 2025), and active participation (Adiwijaya & Palupi, 2024) in the global society (OECD, 2019; World Economic Forum, 2020). This competence is recognized as a core component in both the OECD Learning Framework 2030 and the Partnership for 21st Century Skills, alongside collaboration, communication, and creativity. Despite its importance, Indonesian students continue to exhibit low critical thinking skills, particularly in mathematics. PISA 2018 placed Indonesia 72nd out of 79 countries, with an average score of 379, far below the OECD mean of 489 (OECD, 2023). Similarly, TIMSS 2019 reported that 78% of Indonesian students could only solve lower- to mid-level problems (Yulianto et al., 2024), reflecting persistent reliance on rote memorization and teacher-centered instruction.

This deficiency is especially pronounced in geometry learning at the elementary level, where students struggle with plane figures (Marlissa et al., 2024). Empirical studies indicate that Indonesian fifth-grade students often fail to correctly identify properties of squares, rectangles, triangles, and trapezoids, or to calculate area and perimeter in contextual and non-routine problems (Prahmana et al., 2020; Ramadhani et al., 2019; Putri & Sujadi, 2024). Such challenges suggest that traditional instructional methods limit opportunities for reasoning, analysis, and application, key indicators of critical thinking. Furthermore, students frequently show difficulties in connecting geometric concepts to real-life contexts, such as architectural layouts or agricultural plots, which exacerbates disengagement and hampers problem-solving skills (Prahmana et al., 2020). Therefore, improving critical thinking in elementary geometry is not

merely about mastering formulas but involves developing analytical, evaluative, and inferential skills that enable students to approach geometric problems systematically and creatively.

Addressing the challenge of low mathematical critical thinking among elementary students requires innovative instructional models that combine problem-solving with culturally meaningful contexts (Afriansyah et al., 2020; Tajuddin et al., 2023). Problem-Based Learning (PBL) has been consistently shown to enhance critical thinking through authentic problem scenarios (Rohyati & Purwanto, 2023; Nurmahasih & Jumadi, 2023), while the Flipped Classroom (FC) shifts basic knowledge acquisition to pre-class activities, enabling face-to-face sessions to focus on deeper exploration and collaborative problem solving (Algayres & Triantafyllou, 2020; Yulianto, 2022). Although PBL-FC has demonstrated effectiveness in various contexts, its integration with specific local cultural wisdom in elementary mathematics remains extremely limited. In particular, the application of Baduy local wisdom encompassing traditional agricultural practices, geometric patterns in housing structures, and indigenous measurement systems has scarcely been studied as a scaffolding mechanism for mathematical concepts. By explicitly embedding these culturally grounded examples into the PBL-FC framework, students can engage with mathematics not only as abstract knowledge but also as a contextualized, meaningful activity, fostering both cognitive skills and cultural appreciation. Thus, the present study addresses a significant research gap by exploring how PBL-FC integrated with Baduy local wisdom can enhance mathematical critical thinking among fifth-grade elementary students, providing empirical evidence for a culturally responsive instructional design in Indonesia.

In the Indonesian context, integrating local wisdom such as that of the Baduy community offers authentic sources for developing critical thinking through logical, ecological, and practical values closely tied to students' daily lives. Local culture, traditional practices, and indigenous knowledge can be transformed into contextualized problem scenarios that not only enhance critical thinking but also strengthen students' cultural identity in line with national education goals, 21st-century competencies, and the Sustainable Development Goals (UNESCO, 2020). Furthermore, mathematics instruction is increasingly expected to be evidence-based, measurable, and oriented toward higher-order thinking skills (HOTS). International meta-analyses confirm that PBL consistently improves problem-solving, critical thinking, and collaboration, yielding academic gains of 20 – 25% higher than those achieved with traditional methods (Ulu**ç**ınar, 2023).

Likewise, FC has been found effective in improving student engagement, autonomy, and cognitive outcomes (Lo & Hew, 2021; Strelan et al., 2020; Sosa D í az et al., 2021), with evidence in Indonesia pointing to significant improvements in mathematics achievement and critical thinking (Yulianto et al., 2024). Combining the two (PBL-FC) offers a strategic opportunity to maximize classroom interaction for authentic problem solving and deep discussion (Wang et al.,

2022; Gunawan, 2023). Incorporating Baduy cultural wisdom, ranging from agricultural practices to traditional measurement systems and vernacular architecture, provides cultural scaffolding (Prahmana et al., 2020) that enhances learning relevance, strengthens intrinsic motivation, and enriches students' cultural literacy. Consequently, a PBL-FC model grounded in Baduy local wisdom carries dual potential: advancing mathematical critical thinking while supporting national policies such as the *Profil Pelajar Pancasila* and *Merdeka Belajar* (Kemendikbudristek, 2020), as well as the global agenda of Quality Education (UNESCO, 2020).

Despite being recognized as a key 21st-century competence and foundation for future literacy and global career readiness (World Economic Forum, 2020), critical thinking skills among Indonesian students remain far below international benchmarks (Afriansyah et al., 2021). The 2022 PISA results confirmed persistent gaps in problem solving and mathematical literacy, especially in analytical and inferential skills (OECD, 2023). National reports mirror these findings: the Ministry of Education (Kemendikbud, 2020) emphasized that Indonesian students' critical thinking skills, particularly at the primary level, remain low due to the dominance of routine exercises and memorization. Previous research has also confirmed a strong correlation between critical thinking skills and employability, though mediated by multidimensional factors such as communication and practical experience (Song et al., 2024).

However, empirical studies on critical thinking in elementary mathematics remain limited (Yulianto et al., 2025). Most prior research has focused on secondary education using conventional assessment tools, which fail to fully capture the dynamics of students' cognitive processes. This study, therefore, offers novelty by examining elementary students' critical thinking through non-routine tasks and process-oriented observation, framed within an integrative PBL-FC approach. More importantly, embedding authentic problems grounded in Baduy local wisdom addresses both empirical gaps and national needs while aligning with global perspectives. PBL, as a constructivist approach, enables students to construct knowledge through authentic problem solving, inquiry, reflection, and collaboration. Numerous studies have demonstrated its effectiveness in improving learning achievement, problem-solving abilities, and HOTS (Rohyati & Purwanto, 2023; Nurmahasih & Jumadi, 2023). Uluçınar's (2023) meta-analysis further emphasized its advantages for long-term retention and skill transfer. Yet, its effectiveness is not evenly distributed: low-achieving students often struggle with complex problem contexts (Yulianto et al., 2024), signaling the need for scaffolding, collaboration, and integrated approaches (Hasan, 2020). One promising alternative is the combination of PBL with FC (PBL-FC), which enables higher-order thinking to be conducted in-class through discussion and problem solving, while foundational content is acquired independently through pre-class materials. Empirical evidence confirms that PBL-FC enhances critical thinking and problem solving across diverse contexts (Wang et al., 2022), including Indonesia (Mardiyah & Sunarsi,

2024; Gunawan, 2023). This is particularly relevant given Indonesia' s persistently low performance in mathematical literacy as reported by PISA (OECD, 2023).

Nevertheless, most PBL-FC studies have focused on generic pedagogical aspects without considering students' socio-cultural contexts. Yet, culturally grounded studies suggest that integrating local wisdom strengthens intrinsic motivation and provides meaningful, authentic problems (Dwi et al., 2025). In this regard, Baduy local wisdom offers relevant problem contexts that connect mathematical abstraction with real-life experiences. On the other hand, although FC aligns with scaffolding theory (Gunawan, 2023), digital inequality remains a challenge, as only about 61% of rural students have access to online devices (Samane-Cutipa et al., 2022). This calls for systematic, inclusive, and context-sensitive PBL-FC designs. Hence, this study develops a PBL-FC model grounded in Baduy local wisdom to optimize elementary students' critical thinking. The proposed contribution not only addresses limitations of traditional pedagogies but also enriches mathematics learning with meaningful, contextual, and globally competitive practices.

Despite evidence supporting the effectiveness of PBL and Flipped Classroom (Ramadoni, Aima, & Mardiyah, 2024) in enhancing critical thinking, studies integrating these approaches with local cultural wisdom, specifically the Baduy community practices, remain scarce. Moreover, prior research has predominantly focused on secondary education, generic mathematical contexts, or conventional assessment tools, leaving a significant gap in understanding how culturally contextualized PBL-FC can foster higher-order thinking in elementary geometry. This study addresses these gaps by developing and empirically testing a PBL-FC instructional model grounded in Baduy local wisdom to enhance mathematical critical thinking among fifth-grade students.

Several instructional design frameworks, such as Dick & Carey, Kemp, ADDIE, and ASSURE, have been widely applied to improve the effectiveness and efficiency of learning processes. Among these, the ASSURE model has been recognized for its systematic approach to instructional planning, particularly by emphasizing the analysis of learner characteristics, careful selection of instructional media, and continuous evaluation of learning outcomes (Darllis & Miaz, 2020; Bajracharya, 2019). International evidence further demonstrates its successful application in enhancing science education outcomes (Olayinka et al., 2018; Batır & Sadi, 2021). Despite these advantages, critical reviews indicate that ASSURE often emphasizes media development while insufficiently addressing the integration of local cultural contexts or the stimulation of higher-order thinking, particularly in mathematics. The ASSURE model was selected as the guiding framework for designing the PBL-FC instructional model due to its systematic steps in analyzing learner characteristics, selecting and integrating instructional media, and continuously evaluating learning outcomes. Its adaptability allows the incorporation of culturally grounded

content, such as Baduy local wisdom, into structured learning experiences aimed at enhancing mathematical critical thinking.

In Indonesia, studies employing ASSURE in elementary mathematics education are still limited, especially in content areas requiring critical reasoning, such as geometric topics related to perimeter and area. This gap is particularly concerning because critical thinking is an essential 21st-century skill, emphasized in international assessments like PISA and explicitly prioritized within the Merdeka Belajar curriculum. In light of this, designing instructional models that are not only systematic but also culturally contextual becomes a pressing educational need. To address these gaps, this study proposes the development of a Problem-Based Learning – Flipped Classroom (PBL-FC) instructional model that integrates Baduy local wisdom. The integration of culturally grounded content is strategic, as it provides authentic, meaningful, and contextually relevant learning experiences, fostering students' engagement, motivation, and higher-order mathematical thinking through real-world problem solving. Furthermore, the combination of PBL and the Flipped Classroom allows learners to engage with instructional materials actively at home while focusing on face-to-face classroom interactions on collaborative problem-solving, discussion, and reflection.

The present study systematically investigates the validity, practicality, and effectiveness of the proposed PBL-FC model in elementary mathematics learning. Specifically, the study addresses the following research questions explicitly:

1. How valid is the PBL-FC model integrated with Baduy local wisdom in supporting mathematical critical thinking, as evaluated by expert validators?
2. How practical is the implementation of the PBL-FC model in the classroom, as perceived by teachers and students?
3. To what extent does the PBL-FC model improve students' mathematical critical thinking skills compared to conventional Problem-Based Learning (PBL), across different academic ability levels?

By answering these questions, this study aims to contribute theoretically by advancing instructional design frameworks that are both systematic and culturally contextual, and practically by providing a replicable, evidence-based model for enhancing mathematical critical thinking in Indonesian elementary schools.

2. METHOD

This study employed a research and development (R&D) method using the ASSURE model as the foundation for instructional design. This study employed a research and development (R&D) approach to develop an instructional model, using the ASSURE model as the framework for instructional design. To evaluate the effectiveness of the developed model, a

quasi-experimental design with a pretest – posttest control group was implemented. This design allowed for a systematic comparison between students who experienced the Problem-Based Learning – Flipped Classroom (PBL-FC) intervention and those who followed conventional PBL instruction, enabling the identification of the model' s specific contributions to students' mathematical critical thinking skills. Participants were fifth-grade students from SD Negeri Alaswangi 1, selected based on readiness, prior experience, and technological access, ensuring the internal validity and applicability of the findings.

To rigorously evaluate the effectiveness of the developed instructional model, a quasi-experimental design with a pretest – posttest control group was employed. This design allowed for a controlled comparison between the experimental group (PBL – FC) and the control group (conventional PBL), ensuring that observed differences in mathematical critical thinking could be attributed to the intervention. Pretests were administered to both groups to establish baseline equivalence, followed by posttests after the intervention period to measure gains in critical thinking skills. Statistical analyses included paired-sample t-tests for within-group comparisons and independent-sample t-tests for between-group differences, complemented by normalized gain (N-gain) and effect size (Cohen' s d) calculations. The combined use of a quasi-experimental pretest – posttest control group design and a clearly defined sample size ensures both internal validity and generalizability within the context of elementary mathematics education, aligning with standards for educational intervention research (Campbell & Stanley, 1963; Creswell, 2012).

The model was selected because it aligns with the R&D cycle and has been proven effective in producing instructional designs that are valid, practical, and contextually relevant (Darllis & Miaz, 2020; Bajracharya, 2019; Olayinka et al., 2018; Batır & Sadi, 2021). Specifically, the R&D process in this study followed a systematic iterative cycle as recommended by Borg and Gall (1983) and Pribadi (2011), consisting of: (1) needs analysis to identify learning gaps and contextual requirements; (2) design and development of instructional materials based on the ASSURE framework; (3) expert validation to ensure content and pedagogical relevance; (4) limited trial testing in a small group to evaluate practicality and refine instructional sequences; (5) field testing with the target population to assess effectiveness and engagement; and (6) revision and finalization based on quantitative and qualitative feedback. This comprehensive R&D workflow ensures that the developed instructional model is iteratively refined, contextually grounded, and evidence-based, effectively bridging theoretical design with classroom practice. By explicitly integrating ASSURE within this R&D cycle, the study ensures both structural rigor and cultural relevance, allowing for valid, practical, and 21st-century aligned mathematics learning interventions.

In the Indonesian context, the implementation of the ASSURE model has demonstrated its ability to enhance students' motivation and learning outcomes at the elementary school level (Mardiyah & Sunarsi, 2024; Gunawan, 2023). Accordingly, the adoption of ASSURE in this study is expected to integrate local culture–based learning innovations with the demands of 21st-century literacy. The instructional design development procedure follows the six core stages of the ASSURE model: (1) analyzing learners' characteristics; (2) formulating learning objectives; (3) selecting methods, media, and materials; (4) utilizing media and learning resources; (5) engaging learners actively in the learning process; and (6) conducting evaluation and revision (see Figure 1).

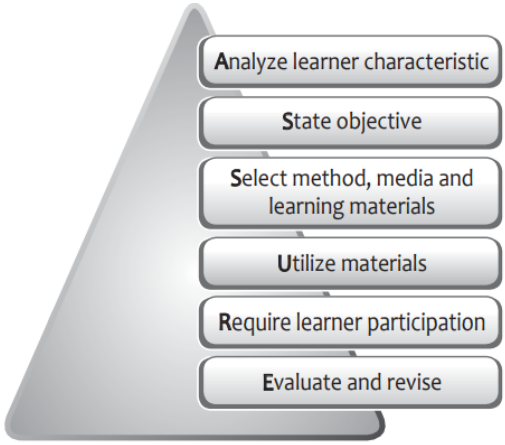

Figure 1. Steps of the ASSURE instructional design model

The research procedure followed six main stages of the ASSURE model, which were adapted to the context of Baduy local wisdom and the characteristics of mathematics learning through the PBL-FC approach:

a. Learner Characteristics Analysis. This analysis covered cognitive aspects, technological readiness, and students' cultural background. Data were collected through questionnaires, teacher interviews, and classroom observations at SDN Alaswangi 1. Initial findings indicated limited access to technology in rural areas; therefore, the Flipped Classroom strategy needed to be realistically designed by combining digital media with printed modules.
b. Formulation of Learning Objectives. The objectives were developed based on critical thinking indicators such as interpretation, analysis, inference, evaluation, and explanation, which are internationally recognized as valid. These indicators were also aligned with the dimensions of the *Profil Pelajar Pancasila* that emphasize critical reasoning.
c. Selection of Methods, Media, and Materials. The integration of PBL and FC was chosen because meta-analytical evidence (Wang et al., 2022; Gunawan, 2023) demonstrates its effectiveness in enhancing higher-order thinking skills (HOTS), motivation, and

achievement. The learning materials were contextualized with Baduy local wisdom, such as agricultural practices, traditional measurement systems, and indigenous house architecture, functioning as cultural scaffolding to bridge formal mathematical concepts with students' cultural experiences.

d. Utilization of Media and Materials. The media included 10 – 15-minute instructional videos, interactive modules, and problem-based student worksheets (LKPD). To address the digital divide, which remains a national issue (UNESCO, 2020), printed modules were provided for students without internet access.

e. Active Student Engagement. Face-to-face sessions focused on group discussions, contextual problem exploration, and solution presentations, ensuring that all students, both high- and low-achieving, were supported through social and academic scaffolding.

Evaluation and Revision. Evaluation was conducted through expert reviews, limited trials, and field testing. Content validity was examined using the Content Validity Ratio (CVR), test reliability with Cronbach's Alpha ($\geq$ 0.8), and construct validity through Exploratory Factor Analysis (EFA). The model's effectiveness was analyzed using paired-sample t-tests, N-Gain scores, and Cohen's d, following international standards for evaluating educational interventions.

Table 1. Application of the ASSURE Model in PBL – FC with the Integration of Baduy Local Wisdom (Geometry Context)

ASSURE Stage	Operationalization in PBL – FC	Integration of Baduy Local Wisdom (Geometry Context)
Analyze Learners	Identify students' prior understanding of two-dimensional shapes (square, rectangle, triangle, trapezoid, parallelogram, circle) and assess their readiness to use technology in the flipped classroom.	Connect geometric shapes to elements of Baduy traditional houses (e.g., triangular roofs, rectangular floors), bamboo weaving patterns (squares/parallelograms), and the spatial layout of villages.
State Objectives	Formulate learning objectives based on critical thinking indicators (Facione, 1990), such as analyzing, evaluating, and solving geometry-related problems.	Objectives are designed to enable students to calculate the area and perimeter of plane figures using Baduy contextual examples, such as determining the area of farmland shaped like a rectangle or trapezoid.
Select Methods, Media, and Materials	Apply the PBL model using authentic problems related to plane geometry, supported by digital media (videos, animations, interactive worksheets) for the flipped classroom.	Contextual materials include: calculating the area of rectangular farmland, designing woven mats shaped like parallelograms, or estimating the area of traditional circular fish ponds.
Utilize Media and Materials	Students study videos and interactive modules at home (flipped phase),	Media include photographs of Baduy farmland, sketches of traditional houses, bamboo weaving patterns, and videos

ASSURE Stage	Operationalization in PBL – FC	Integration of Baduy Local Wisdom (Geometry Context)
	then discuss problem-solving during face-to-face sessions.	depicting Baduy agricultural activities that illustrate geometric concepts.
Require Learner Participation	Organize group discussions to solve real-world geometry-based problems, followed by solution presentations and critical reflection.	For example, students calculate: the area of a trapezoidal rice field, the number of bamboo sticks needed for a rectangular woven mat, or the circumference of a traditional circular well.
Evaluate and revise	Evaluate mathematical critical thinking tests (based on Facione's indicators), observation of learning activities, and questionnaires for both students and teachers.	Evaluation instruments include culturally contextualized Baduy problems, such as measuring land-use efficiency of farmland in the form of plane figures within local agricultural practices.

The integration of the ASSURE model with the Problem-Based Learning – Flipped Classroom (PBL – FC) approach in teaching plane geometry to fifth-grade elementary school students was designed to address the limitations of conventional methods, which tend to be abstract. Through the ASSURE framework (Pribadi, 2011), the learning process was systematically structured, beginning with an analysis of student characteristics and continuing through to ongoing evaluation. This integration was enriched with an ethnomathematics approach (Prahmana et al., 2020), ensuring that geometric concepts were not taught in isolation from cultural realities but were contextualized through Baduy community artifacts, such as traditional house structures, bamboo weaving patterns, and agricultural land layouts.

In the flipped classroom phase (Lo & Hew, 2the eva021; Strelan et al., 2020; Sosa D í az et al., 2021), students engaged with learning materials through videos and interactive modules at home, allowing face-to-face sessions to focus on real-world problem-solving based on PBL principles (Wang et al., 2022). For example, students were tasked with calculating the area of trapezoid-shaped fields or determining the perimeter of rectangular woven mats. This approach was expected to foster more meaningful, contextual learning while simultaneously cultivating students' critical thinking skills.

The participants were fifth-grade students from SD Negeri Alaswangi 1 during the second semester of the 2024/2025 academic year. Participants consisted of 60 fifth-grade students from SD Negeri Alaswangi 1, divided equally into an experimental group (n = 30) that received the Problem-Based Learning – Flipped Classroom (PBL – FC) intervention and a control group (n = 30) that received conventional PBL instruction. The sample size was determined based on power analysis (Cohen, 1988), ensuring sufficient statistical power (⩾ 0.80) to detect medium effect sizes for differences in mathematical critical thinking outcomes. Participant selection was based on four methodological criteria: (1) student characteristics aligned with the research objectives,

particularly those who had not previously experienced integrated thematic instruction and demonstrated varied levels of motivation; (2) a conducive school environment with adequate facilities and access to technology to support the FC model; (3) teacher readiness to act as facilitators of innovative learning; and (4) institutional approval through active support from the school principal and classroom teachers. These criteria were established to ensure internal validity as well as the sustainability of model implementation.

The research instruments were developed through a validation and reliability testing process to ensure data accuracy. The instruments included:

a. Mathematical Critical Thinking Test. The test was developed based on Facione's six indicators of critical thinking (interpretation, analysis, evaluation, inference, explanation, and self-regulation) and contextualized with Baduy local wisdom in mathematics topics such as plane geometry and measurement. The instrument consisted of 25 items: 10 multiple-choice complex items, 8 short-answer items, and 7 essay items, each designed to measure specific Facione indicators. For instance, an interpretation item asked students to describe the geometric pattern of Baduy traditional house roofs; an analysis item required comparing area calculations of trapezoidal and rectangular rice fields; an inference item asked students to predict outcomes of combining different woven mat shapes; an evaluation item required students to assess the efficiency of land usage based on traditional practices; an explanation item asked for reasoning behind their solution steps; and a self-regulation item involved reflecting on their problem-solving strategy. Content validity was confirmed by four experts (two in mathematics education and two in local culture), using both qualitative feedback and Content Validity Ratio (CVR) ≥ 0.80. Reliability was calculated with Cronbach's alpha, yielding $\alpha = 0.87$, indicating high internal consistency.
b. Implementation Observation Sheet – designed to assess the fidelity of PBL – FC implementation, presented in a Likert-scale rubric with indicators including student engagement, clarity of instructional flow, and consistency in integrating local cultural elements.
c. Student and Teacher Questionnaires – employed to measure practicality, acceptance, and motivation. The questionnaire items were developed based on Self-Determination Theory and the Technology Acceptance Model (TAM), covering aspects such as perceived usefulness, ease of use, engagement, and meaningfulness of learning.

Data analysis employed a concurrent triangulation mixed-methods approach to integrate quantitative and qualitative findings complementarily:

a. Quantitative Analysis involved prerequisite testing (Shapiro – Wilk normality test and Levene's homogeneity test) followed by a paired t-test to assess pre- and post-

implementation differences. Effectiveness was further examined using normalized gain (N-gain) and Cohen' s d effect size. Where group differences emerged, an ANOVA test was conducted to provide a more robust comparative perspective.

b. Qualitative analysis was conducted using a systematic interactive approach based on Miles & Huberman (2014), comprising three main stages:
   1) Data Reduction: Interview transcripts, field notes, and observational records were systematically coded using open, axial, and selective coding. Open coding identified initial concepts, axial coding established relationships among codes, and selective coding synthesized overarching themes.
   2) Data Display: The codes and categories were organized into categorization matrices, explicitly linking learning practices, instructional implementation, and Baduy cultural values.
   3) Thematic Conclusion Drawing and Verification: Patterns and relationships were examined to formulate meaningful themes about the integration of culture and mathematics learning. To strengthen validity, methodological triangulation was applied by cross-verifying findings from observations, interviews, and documentation, and source triangulation involved teachers, students, and local cultural experts. Member checking was also conducted to confirm the accuracy of interpretations and ensure credibility.

3. RESULT AND DISCUSSION

This section presents the research findings along with a comprehensive discussion. The results are displayed in various forms, such as figures, graphs, and tables, to facilitate readers' understanding. The discussion is organized into several sub-sections.

a. Research Findings

The learning process was primarily focused on collaborative discussions, contextual problem-solving, and argumentative presentations, all of which fostered higher-order cognitive engagement. Formative – summative evaluations, supported by reflection, revision, and expert validation, ensured the quality of content, practicality of implementation, and pedagogical effectiveness. Expert validation confirmed the model as *"highly feasible"*, with the most prominent indicators being student engagement and the contextual relevance rooted in local cultural values. The practicality test revealed positive responses from both students and teachers. Students reported that the integration of local wisdom enhanced their motivation and active participation, while teachers considered the design easy to implement due to the flexibility of the media. Therefore, the Baduy local wisdom – based PBL-FC model is deemed suitable as a strategy to optimize students' critical thinking skills, as it combines cognitive aspects with the

internalization of contextual, relevant, and meaningful cultural values. The contribution of this study is twofold: (1) practical, in the form of an innovative lesson plan (RPP) that is easily applicable in classroom practice; and (2) theoretical, by offering a hybrid PBL-FC model grounded in local wisdom as an alternative pedagogical reconstruction for contextual mathematics education (see Table 2).

Table 2. Validation Results, Revisions, and Suggestions for Improvement of the PBL-FC Learning Design

Evaluated Aspect	Validation Results (Score/Interpretation)	Validator's Corrections and Notes	Suggestions for Improvement
Alignment of Learning Objectives	3.80 (Very Good)	Critical thinking indicators are already included, but the domains of interpretation and evaluation need to be made explicit.	Clarify the formulation of critical thinking indicators by Facione's framework (1990) and the Pancasila Student Profile.
Relevance of Content to Baduy Local Wisdom	3.75 (Good)	The material is contextual (agriculture, architecture, measurement systems), but lacks non-routine problems.	Add HOTS-based problem examples rooted in the Baduy context to make the tasks more challenging and diverse.
Appropriateness of PBL-FC Methods and Strategies	3.90 (Very Good)	The pre-learning sequence is clear, but it requires stronger monitoring mechanisms before class.	Develop monitoring sheets or short quizzes to ensure the implementation of pre-learning activities.
Learning Media and Worksheets (LKPD)	3.70 (Good)	The pre-class video is appropriate, but the printed module contains limited illustrations.	Incorporate more visual illustrations of Baduy culture to strengthen the contextual learning environment.
Student Engagement (Learning Activities)	3.85 (Very Good)	Group discussions are effective, but remain dominated by high-achieving students.	Design additional scaffolding for lower-achieving students, such as step-by-step problem-solving guides.
Practicality of Teacher Implementation	3.80 (Very Good)	Teachers can apply the lesson plan (RPP), but require more detailed technical instructions.	Provide a concise teacher's guide within the lesson plan to facilitate implementation.

Evaluated Aspect	Validation Results (Score/Interpretation)	Validator's Corrections and Notes	Suggestions for Improvement
Evaluation and Assessment Instruments	3.75 (Good)	The critical thinking test is relevant, but the observation rubric is insufficiently detailed.	Refine the assessment rubric by adding specific indicators for analysis, inference, and evaluation.

Average Validation Score = 3.80 (Category: Very Good)

The assessment aspects of the lesson plan (RPP) in this study included identity, the formulation of learning objectives, the procedural steps of the Problem-Based Learning – Flipped Classroom (PBL-FC) model, and the assessment instruments designed based on critical thinking indicators. Expert validation results indicated an average score of 87.5%, which falls into the category of *"highly valid" (A)* according to the conversion criteria of 85.01% – 100%. These findings affirm that the lesson plan design not only meets technical feasibility requirements but also possesses a solid pedagogical foundation for the implementation of the PBL-FC model integrated with Baduy local wisdom. Accordingly, the developed lesson plan can be considered a valid and contextual learning guide with the potential to foster students' critical thinking skills.

Table 3. Validation Results of the Lesson Plan (RPP) by Expert Validators

Assessed Aspect	Assessment Indicators	Mean Score	%	Category	Remarks
RPP Identity	Completeness of identity (subject, grade, semester, time allocation, etc.)	3.5	87.5	Highly Valid	Clearly stated, aligned with the curriculum and local context
Learning Objectives	Alignment with critical thinking indicators (interpretation, analysis, inference, evaluation, explanation)	3.6	90.0	Highly Valid	Objectives consistent with the *Profil Pelajar Pancasila* and HOTS
PBL-FC Learning Steps	Integration of PBL syntax (problem orientation, investigation, discussion, presentation) and FC components (pre-learning, collaborative face-to-face sessions)	3.4	85.0	Highly Valid	Well-integrated with the Baduy local wisdom
Media/Material Selection & Utilization	Relevance of media (videos, modules, worksheets) to authentic problems rooted in the Baduy culture	3.5	87.5	Highly Valid	Contextual media supporting scaffolding
Assessment & Evaluation	Appropriateness of instruments (non-routine essay tests, critical thinking rubrics) to learning objectives	3.6	90.0	Highly Valid	Authentic assessment measuring critical thinking skills

Assessed Aspect	Assessment Indicators	Mean Score	%	Category	Remarks
Overall Average		3.5	87.5%	Highly Valid	Feasible for use as an innovative learning guide

Based on Table 3, the validation results, the PBL-FC lesson plan integrated with Baduy local wisdom achieved an average score of 87.5%, categorized as highly valid. This indicates that the lesson plan met the criteria of identity clarity, goal clarity, syntactical appropriateness, media relevance, and authenticity of assessment, in line with the validation standards for learning tools. Accordingly, the lesson plan is deemed suitable as a guideline for implementing culturally contextual learning. However, it should be noted that instrument validity does not automatically guarantee effectiveness in improving learning outcomes, thereby necessitating further testing at the classroom implementation level.

In terms of practicality, the implementation of the lesson plan, as well as teacher and student responses, yielded positive results. The implementation score reached 3.87 (97.08%), which falls into the "highly practical" category, indicating that the instructional stages (introduction, main activities, and closure) were well-aligned and easy to apply. These findings are consistent with the practicality criteria suggested by Plomp and Nieveen (2010), namely consistency of implementation and user acceptance. Nonetheless, the claim of practicality still requires further examination in more diverse classroom settings to ensure that its effectiveness is not limited to the trial conditions (see Table 4).

Table 4. Implementation Test Results of the Lesson Plan on Theme 8, Grade V Elementary School

Evaluated Aspect	Assessment Indicator	Average Score	Percentage (%)	Category
Introduction	Apperception, motivation, and communication of objectives	3.85	96.25	Highly Practical
Main Activities	PBL-FC: discussion, collaboration, problem-solving	3.88	97.22	Highly Practical
Closure	Reflection, summary, follow-up	3.89	97.78	Highly Practical
Overall Average		3.87	97.08	Highly Practical

Pribadi (2017) emphasized that students who actively engage in learning tend to construct meaningful knowledge, whereas passive learners often demonstrate lower curiosity and learning motivation. This finding is relevant to the present study, particularly in relation to the implementation of the developed lesson plans (RPP). Based on questionnaires completed by

two classroom teachers, the RPP obtained an average score of 3.67 with a practicality percentage of 91.67%, categorized as "very good." These results indicate that the RPP is not only practically feasible but also has the potential to support more student-centered learning strategies. Although the evaluation was limited to teacher responses, the developed product shows a positive contribution in strengthening the teacher's role as a facilitator and in fostering greater student engagement in critical thinking and independent learning.

Table 5. Teacher Responses to the Developed RPP

No	Assessment Aspect	Mean Score	Percentage (%)	Category
1	Clarity of learning objectives	3.8	95.0	Very Practical
2	Alignment of materials with objectives	3.7	92.5	Practical
3	Coherence of learning steps	3.6	90.0	Practical
4	Relevance of media and learning resources	3.7	92.5	Practical
5	Implementability of the lesson plan (RPP)	3.8	95.0	Very Practical
6	Ease of use for teachers	3.6	90.0	Practical
Average		**3.67**	**91.67**	**Practical**

Based on Table 5, a student response questionnaire was also administered to all fifth-grade students to evaluate the practicality and acceptance of the learning model. The analysis showed an average response percentage of 86.16%, categorized as "very good" (Riduwan, 2012). This finding reflects a positive reception of the Baduy local wisdom – based PBL-FC model, which was considered to facilitate material comprehension and enhance learning motivation. The high percentage further supports the effectiveness of contextual and student-centered learning, as highlighted by Ramadhani et al. (2019) and UNESCO (2020). Therefore, the very good student responses not only confirm the initial practical validity of the model but also suggest its potential for replication in other elementary school contexts.

Table 6. Student Responses

No	Evaluation Aspect	Percentage (%)	Category
1	Clarity of material presentation	85.5	Very Good
2	Student engagement in learning	87.2	Very Good
3	Ease of concept comprehension	86.8	Very Good
4	Relevance to daily life	85.9	Very Good
5	Motivation to learn after using the model	85.3	Very Good
Average		86.16	Very Good

Based on Table 6, the findings indicate a positive reception from students toward the PBL-FC model integrated with Baduy local wisdom, which was perceived as facilitating comprehension of the subject matter and enhancing learning motivation. The high percentage of

favorable responses further supports the effectiveness of contextual, student-centered learning as emphasized by UNESCO (2020). Thus, the students' strong responses not only demonstrate the initial practical validity of the model but also suggest the potential for replication in other primary school contexts.

To complement these quantitative findings, a qualitative analysis was also conducted. Data were obtained through interviews with teachers, students, and local Baduy cultural experts, and analyzed in three stages: (1) data reduction through open coding of interview transcripts and field notes to identify emerging themes; (2) data presentation in the form of categorization matrices linking learning practices with Baduy cultural values (e.g., agricultural systems, traditional house architecture, and ecological wisdom); and (3) thematic conclusion drawing regarding the contribution of cultural contexts to the learning process. The validity of the findings was strengthened through methodological triangulation (observation, interviews, documentation) and source triangulation (teachers, students, local cultural experts). The analysis revealed that integrating Baduy cultural wisdom enhanced intrinsic motivation, student engagement in discussions, and the perceived relevance of mathematics to everyday life. Qualitative data were obtained through interviews with teachers, students, and local cultural experts. Data were reduced via open coding, categorized according to learning practices and Baduy cultural values, and presented thematically. Triangulation was used to ensure validity.

To evaluate the effectiveness of the PBL-FC model integrated with Baduy local wisdom in enhancing students' critical thinking skills, a comparative analysis was conducted between pretest and posttest results of the experimental group (PBL-FC) and the comparison group (PBL). This analysis, based on a quasi-experimental design as recommended by Campbell and Stanley (1963), allowed the identification of the specific contribution of the model to students' improvement, as summarized in Table 7.

Table 7. Comparison of Pretest and Posttest Distribution of Critical Thinking Skills by Learning Model

Interval	PBL-FC (Pretest)			PBL (Pretest)			PBL-FC (Posttest)		PBL (Posttest)		
	T	S	R	T	S	R	T	S	T	S	R
31 – 35	–	1	2	–	1	1	–	–	2	–	1
36 – 40	1	1	3	–	3	2	–	1	3	–	2
41 – 45	2	2	4	–	1	2	–	6	2	4	2
46 – 50	–	–	–	–	1	–	–	–	1	4	1
51 – 55	2	6	–	4	7	–	–	7	2	4	–
56 – 60	3	4	–	2	6	–	–	3	–	4	–
61 – 65	5	3	–	3	3	–	–	1	–	–	–
66 – 70	–	–	–	–	–	–	–	1	–	–	2
71 – 75	–	–	–	–	–	–	–	6	–	4	2
76 – 80	–	–	–	–	–	–	1	7	1	4	1

Interval	PBL-FC (Pretest)			PBL (Pretest)			PBL-FC (Posttest)		PBL (Posttest)		
	T	S	R	T	S	R	T	S	T	S	R
81 – 85	–	–	–	–	–	–	1	3	2	4	–
86 – 90	–	–	–	–	–	–	5	1	–	3	–
91 – 95	–	–	–	–	–	–	2	2	–	2	–
Total	10	17	9	9	22	5	9	20	8	20	6

Table 7 presents the comparative distribution of students' critical thinking skills between the experimental group (PBL-FC integrated with Baduy local wisdom) and the comparison group (conventional PBL) at both the pretest and posttest stages. At the pretest stage, both groups were relatively homogeneous, with the majority of students falling into the moderate category (17 students in the PBL-FC group and 22 students in the PBL group), while a considerable proportion remained in the low category. This initial condition confirms the appropriateness of comparing the two groups on a valid basis. Following the intervention, a sharper distribution shift was observed in the PBL-FC group: the number of students in the low category decreased substantially, while those in the high category increased significantly, particularly within the 86 – 95 interval (7 students). In contrast, although the PBL group also demonstrated improvement, the distribution remained more dispersed, with 6 students still in the low category. This pattern indicates that integrating PBL-FC with local wisdom was not only effective in elevating students from the low to the moderate category but also successful in enabling high-achieving students to attain optimal performance.

The distribution of critical thinking scores before and after intervention is summarized in Table 7. In the pretest, most students fell into the moderate category (17 in PBL-FC, 22 in PBL). After the intervention, the PBL-FC group showed an increase in the number of students in the high category (86 – 95 interval: 7 students), whereas the PBL group showed a less pronounced shift (Bishop & Verleger, 2013), and that incorporating local contexts reinforces the relevance of learning (Gay, 2010). Nevertheless, distribution alone provides only a general tendency. Therefore, the mean score analysis of the pretest – posttest, as presented in Table 8, is required to provide a more comprehensive picture of the relative effectiveness of both instructional models.

Table 8. Comparison of Pretest, Posttest, Gain, and Percentage Increase in Students' Critical Thinking Skills in the PBL-FC and PBL Models

Learning Model	Pretest	Posttest	Gain	Improvement (%)
PBL-FC Integrated with Baduy Local Wisdom	47.31	82.28	34.97	73.91%
Conventional PBL	49.14	76.92	27.92	56.83%

Table 8 presents a comparison of the mean pretest, posttest, gain scores, and percentage improvement in students' critical thinking skills between the experimental group (PBL-FC) and the comparison group (PBL). The experimental group (PBL-FC integrated with Baduy local wisdom) achieved a mean pretest score of 47.31 and a posttest score of 82.28, resulting in a gain of 34.97 points (73.91%). The comparison group (conventional PBL) had a pretest mean of 49.14 and a posttest mean of 76.92, with a gain of 27.92 points (56.83%) (Table 8). Paired-sample t-tests indicated significant differences between pretest and posttest scores for both groups: PBL-FC ($t = 12.45$, $p < 0.001$) and PBL ($t = 9.87$, $p < 0.001$). N-Gain analysis showed a mean normalized gain of 0.74 (high) for PBL-FC and 0.57 (medium) for PBL. Cohen's d effect size for PBL-FC was 1.25 (large) and 0.78 (medium) for PBL. Prior to inferential analysis, assumption testing was conducted using the Shapiro – Wilk normality test and Levene's homogeneity test. The results confirmed that the data were normally distributed and homogeneous, making them suitable for further analysis. Subsequently, paired-sample t-tests were employed to compare the pretest and posttest scores within both groups. The results indicated significant differences ($p < 0.001$) in both the PBL-FC and PBL groups, suggesting that critical thinking skills improved after instruction. However, the improvement in the PBL-FC group was consistently higher than that of the PBL group.

An N-Gain analysis reinforced these findings, showing that the PBL-FC group achieved an average score of 0.74 (high category), whereas the PBL group obtained 0.57 (medium category). Moreover, effect size analysis using Cohen's *d* yielded a value of 1.25 (large effect), indicating that the impact of the PBL-FC model on students' critical thinking skills was substantial. To further examine the relative contribution of each model, ANOVA was conducted, revealing a significant difference between groups ($F = 5.100$; $p < 0.001$). Post hoc tests confirmed that the PBL-FC group significantly outperformed the PBL group. Thus, the effectiveness of the PBL-FC model was supported not only descriptively but also inferentially, with a strong effect size.

To complement the descriptive findings in Table 9, paired-sample t-tests were conducted for each group. The results demonstrated significant differences between pretest and posttest scores in both the PBL-FC group ($t = 12.45$; $p < 0.001$) and the PBL group ($t = 9.87$; $p < 0.001$). These findings confirm that both instructional models contributed positively to the enhancement of students' critical thinking skills, although the PBL-FC group exhibited statistically greater improvement.

Further analysis of effectiveness using normalized gain (N-Gain) revealed that the PBL-FC group achieved a high category ($g = 0.74$), while the PBL group remained in the medium category ($g = 0.56$). Additionally, the effect size (Cohen's *d*) for the PBL-FC group reached 1.21 (large effect), compared to 0.78 (medium effect) for the PBL group. These values indicate that the implementation of the PBL-FC model, integrated with Baduy local wisdom, had a stronger

impact on student outcomes than conventional PBL. Collectively, these inferential results align with the distribution of scores in Tables 6 – 7, reinforcing the claim that culturally grounded pedagogical innovation is not only statistically significant but also practically meaningful. The quantitative evidence underscores that integrating PBL-FC with Baduy local wisdom can optimize students' critical thinking skills through a contextual, representative, and 21st-century relevant instructional approach. After comparing the overall effectiveness of the PBL-FC and PBL models, the next analysis focused on students' achievements based on academic ability levels. This approach was crucial to determine the extent to which improvements in critical thinking skills occurred proportionally among high-, medium-, and low-ability students. Students in the low academic ability category achieved a mean gain of 32.23 points, whereas the medium-ability group gained 28.13 points, and the high-ability group gained 30.55 points (Table 9).

Table 9. Comparison of Mean Pretest and Posttest Scores of Students' Critical Thinking Skills Based on Initial Academic Ability

Academic Ability Level	Pretest	Posttest	Gain
High	56.67	87.22	30.55
Medium	48.22	76.35	28.13
Low	36.15	68.38	32.23

The results presented in Table 9 indicate that all categories of students' academic ability experienced an increase in pretest – posttest scores of critical thinking. The high-ability group improved by an average of 30.55 points, the medium group by 28.13 points, and the low-ability group by 32.23 points. Interestingly, students with low academic ability demonstrated the greatest improvement. This finding suggests that the Baduy local wisdom – based PBL-FC model is not only relevant for high-achieving students but also particularly effective in supporting lower-ability groups. This phenomenon can be explained through the concept of *cultural scaffolding* (Vygotsky, 1978), in which learning is connected to familiar socio-cultural contexts, thereby facilitating students' comprehension.

However, the analysis in Table 10 remains aggregate in nature and does not provide a direct comparison with the conventional PBL model. To obtain a clearer picture of the relative contributions of the two models, Table 10 presents a comparative analysis of score improvements across academic ability levels, thereby allowing for a more valid evaluation of the specific effectiveness of the PBL-FC approach.

Table 10. Comparison of Average Pretest – Posttest Score Gains in Critical Thinking by Academic Ability Level under PBL-FC and PBL

Learning Model	Academic Ability	Pretest	Posttest	Gain	Relative Increase
PBL-FC	Low	37.24	70.50	33.26	Highest
	High	58.51	89.30	30.79	Medium

Learning Model	Academic Ability	Pretest	Posttest	Gain	Relative Increase
	Medium	50.26	78.25	27.99	Lowest
PBL	Medium	48.28	78.35	30.07	Highest
	High	54.83	83.14	28.31	Medium
	Low	35.06	61.16	26.10	Lowest

The analysis in Table 10 shows that the improvement in students' critical thinking ability varies according to academic ability level within each instructional model. Nevertheless, this description remains aggregate and does not fully capture the interaction between variables. To address this, factorial analysis was employed, enabling a more precise examination of differences between models as well as the interaction with academic ability categories. Accordingly, Table 11 presents a comparison of mean critical thinking scores across PBL-FC and PBL, categorized by academic ability (high, medium, low), and further reports the marginal means as the basis for interpreting both main effects and the interaction effect between instructional model and academic ability.

Table 11. ANOVA Results on Critical Thinking Ability

Factor	df	Mean Square	F	Sig.
Critical Thinking Ability	2	794.890	17.536	$p < 0.001$
Instructional Model (PBL-FC)	1	231.163	5.100	$p < 0.001$
Interaction (Ability × Model)	2	95.190	2.100	$p < 0.001$

The ANOVA results indicate that students' academic ability significantly influences learning achievement ($F = 17.536$; $p < 0.001$), as does the instructional model, including PBL-FC ($F = 5.100$; $p < 0.001$). Furthermore, a significant interaction between academic ability and instructional model was found ($F = 2.100$; $p < 0.001$), suggesting that the effectiveness of PBL-FC varies according to students' ability levels. This aligns with the principles of differentiated instruction and the zone of proximal development. Since ANOVA only reveals overall differences, post hoc pairwise comparisons were conducted to identify which groups differed significantly in terms of critical thinking ability. The results, summarized in Table 10, confirm significant differences across the high-, medium-, and low-ability groups.

Table 12. Post Hoc Test of Academic Ability on Learning Achievement

Academic Ability Comparison	Mean Difference	Sig.	Conclusion
High – Medium	9.76	0.001	Significant difference
High – Low	19.83	0.000	Significant difference
Medium – Low	10.06	0.002	Significant difference

The post hoc test (Table 12) indicates significant differences in learning achievement among students with different levels of critical thinking ability. High-ability students consistently

scored higher than their medium- (Δ = 9.76; p = 0.001) and low-ability peers (Δ = 19.83; p < 0.001). The difference between medium- and low-ability groups was also significant, though smaller (Δ = 10.06; p = 0.002). These findings confirm a substantial achievement gap between students at the extremes of critical thinking ability, which is highly relevant for strategies of differentiation and ability-based instructional interventions.

b. Discussion

A critical aspect of this study' s novelty lies in the role of Baduy local wisdom as cultural scaffolding. The integration of indigenous knowledge manifested through traditional agricultural practices, measurement systems, and architectural logic provided an authentic context that anchored abstract mathematical concepts in students lived experiences. This scaffolding effect was particularly beneficial for lower-ability students, as it reduced cognitive load, increased comprehension, and allowed them to engage in higher-order thinking within familiar cultural frames. By embedding PBL-FC activities in these culturally relevant contexts, students were able to connect problem-solving tasks to meaningful, real-world scenarios, which strengthened intrinsic motivation and facilitated equitable access to learning outcomes. Thus, the Baduy local wisdom component did not merely contextualize content but functioned as a strategic mediating mechanism that enhanced the effectiveness of the PBL-FC model across heterogeneous ability levels.

The ANOVA results (Table 11) indicate that both academic ability and learning models exert a significant influence on students' critical thinking achievement. The higher gains in the PBL-FC group suggest that integrating Baduy local wisdom and Flipped Classroom techniques can effectively enhance critical thinking skills across all ability levels. Cultural scaffolding may facilitate comprehension, particularly for lower-ability students (Vygotsky, 1978). Cultural scaffolding may facilitate comprehension, particularly for lower-ability students (Vygotsky, 1978). A critical aspect of this study' s novelty lies in the role of Baduy local wisdom as cultural scaffolding. The integration of indigenous knowledge manifested through traditional agricultural practices, measurement systems, and architectural logic provided an authentic context that anchored abstract mathematical concepts in students lived experiences. This scaffolding effect was particularly beneficial for lower-ability students, as it reduced cognitive load, increased comprehension, and allowed them to engage in higher-order thinking within familiar cultural frames. By embedding PBL-FC activities in these culturally relevant contexts, students were able to connect problem-solving tasks to meaningful, real-world scenarios, which strengthened intrinsic motivation and facilitated equitable access to learning outcomes. Thus, the Baduy local wisdom component did not merely contextualize content but functioned as a strategic mediating

mechanism that enhanced the effectiveness of the PBL-FC model across heterogeneous ability levels.

The significant interaction between these two variables suggests that the effectiveness of the PBL-FC model is differential; students' outcomes are determined not only by the learning model but also by their initial ability levels. This finding is consistent with Gunawan (2023), who emphasized that the integration of PBL and the flipped classroom provides learning flexibility through adaptive facilitation. Consequently, this model necessitates personalized strategies, ensuring that low-ability students receive adequate scaffolding while high-ability students are provided with further cognitive challenges. These results are reinforced by Mardiyah and Sunarsi (2024) and Nurmahasih and Jumadi (2023), who demonstrated that the effectiveness of PBL is highly dependent on students' cognitive readiness and learning context. Thus, the empirical evidence of this study underscores that the success of PBL-FC is not uniform but should be managed differentially to align with the principle of equity in education and to support differentiated instruction as emphasized in the Merdeka Curriculum. Expert evaluation of the ASSURE-based instructional design confirmed that each component was consistent with critical thinking indicators, thereby strengthening the validity of the instructional framework. This aligns with the findings of Bajracharya (2019), Batır and Sadi (2021), and Darllis et al. (2020), who affirmed the reliability of the ASSURE model in supporting problem-based learning. The integration of PBL-FC with Baduy local wisdom in this study contributes a novel dimension by connecting the effectiveness of a modern instructional design framework with an authentic cultural context.

The field trials revealed positive acceptance from both teachers and students. Teachers perceived the instructional procedures as realistic and applicable, albeit requiring more intensive facilitation and the support of simple print and digital learning resources. This finding resonates with UNESCO's (2020) report, which underscores the importance of inclusion and infrastructure readiness in implementing pedagogical innovations. Meanwhile, students found it easier to understand abstract mathematical concepts through contextual representations grounded in Baduy culture. Teachers and students acknowledged that the Baduy cultural elements served as effective scaffolds that made abstract concepts tangible, supporting differentiated instruction and enabling low-ability students to actively participate in problem-solving tasks. For teachers, the PBL-FC model integrated with Baduy local wisdom offers a structured yet flexible instructional framework, providing guidance for scaffolding students' critical thinking across varying ability levels. Teachers can adapt pre-class materials, collaborative tasks, and assessment rubrics to suit their classroom context, particularly when addressing low-ability learners. For schools, the findings suggest that embedding local cultural values in the curriculum can enhance student engagement and motivation, while also promoting equitable learning

opportunities. School management may consider incorporating training on culturally responsive pedagogy, as well as investing in accessible digital and printed resources, to facilitate the effective implementation of the PBL-FC model. This supports the principles of culturally responsive pedagogy (Prahmana et al., 2020; Yulianto et al., 2024), whereby the integration of local culture not only enhances cognitive comprehension but also fosters intrinsic motivation and emotional engagement in learning. Accordingly, these findings not only confirm the validity of the ASSURE model in designing problem-based instruction but also expand the international literature on culturally grounded PBL-FC approaches. The academic implication is the need to reconstruct instructional design frameworks that are adaptive, inclusive, and culturally embedded to address the challenges of equity and quality in 21st-century education.

The inferential findings are consistent with the distribution of scores (Tables 7 – 8), which show a significant shift from the low to the high category among the PBL-FC group. Effectiveness analysis revealed that PBL-FC produced a high N-Gain (0.74) with a large effect size (d = 1.21), whereas PBL alone was only in the moderate category (g = 0.56; d = 0.78). These findings corroborate the meta-analyses of Strelan et al. (2020) and Uluçınar (2023), which confirmed that the combination of PBL and flipped classroom exerts a substantial impact on learning outcomes across disciplines. Theoretically, these results further strengthen the validity of the ASSURE model (Pribadi, 2011; Bajracharya, 2019; Olayinka et al., 2018), which emphasizes the integration of instructional strategies to facilitate higher-order thinking skills.

Moreover, the practicality and acceptance tests from teachers and students revealed that the instructional design was not only conceptually sound but also feasible for implementation in elementary schools. The integration of Baduy local wisdom served as cultural scaffolding (Hasan, 2020; Prahmana et al., 2020), which not only contextualized abstract concepts but also reduced cognitive load, enhanced students' emotional engagement, and strengthened their intrinsic motivation to learn mathematics. Thus, both the quantitative and qualitative evidence highlight the contribution of this study: proposing a culturally integrated PBL-FC model that is effective, valid, and practical in enhancing elementary students' critical thinking, while also offering new perspectives on culturally responsive pedagogy within the framework of the *Merdeka Curriculum*.

The analysis of Table 10 shows disparities in critical thinking outcomes across academic ability groups: High vs. Medium differed by 9.76 points ($p = 0.001$); High vs. Low by 19.83 points ($p < 0.001$); and Medium vs. Low by 10.06 points ($p = 0.002$). These findings highlight the importance of equity in education, whereby low-ability students require more structured pedagogical interventions through scaffolding, step-by-step guidance, and small-group collaboration (Hasan, 2020; OECD, 2023). Instructional differentiation strategies thus become essential to ensure equal learning opportunities for all students, as emphasized in the *Merdeka*

Curriculum and the *Profil Pelajar Pancasila* (Ministry of Education and Culture Regulation, 2020; Nurmahasih & Jumadi, 2023).

The integration of Baduy cultural contexts through agricultural practices, traditional measurement, and indigenous architecture functioned as cultural scaffolding that not only enhanced content relevance but also reinforced students' emotional engagement (Prahmana et al., 2020). This is consistent with the findings of Lo and Hew (2021) and Yulianto (2022, 2025), who demonstrated that learning combining cultural contexts with digital technology can enhance intrinsic motivation and academic self-efficacy. Therefore, the outcomes of this study offer dual contributions: practically, they illustrate how culturally integrated PBL-FC can reduce achievement gaps across student groups; and theoretically, they extend the literature on culturally responsive pedagogy in primary mathematics education in Indonesia. The findings of this study contribute to the advancement of contextual mathematics learning theory by demonstrating that integrating culturally grounded practices (Baduy local wisdom) with contemporary pedagogical frameworks such as PBL-FC, enhances higher-order thinking skills. This evidence suggests that the theoretical construct of contextual learning should not only emphasize real-world problem contexts but also incorporate local cultural values as scaffolding mechanisms. Consequently, contextual learning theory can be extended to integrate cultural responsiveness as a core principle, emphasizing the synergy between cognitive development and socio-cultural immersion.

Nonetheless, this study also reveals disparities in outcomes across academic ability groups (Table 10), underscoring the urgency of applying differentiated instruction to reduce achievement gaps. This finding is consistent with Gunawan (2023) and Rohyati & Purwanto (2023), who argue that the effectiveness of both PBL and PBL-FC is strongly influenced by students' cognitive readiness, requiring adaptive, layered pedagogical interventions (scaffolding). Hence, instruction should not merely aim for average performance but must ensure equity in education by providing tailored support for low-ability learners. From a policy perspective, these findings reinforce the direction of the *Merdeka Curriculum*, which emphasizes flexibility, differentiation, and the integration of local cultural values as strategies to improve the quality of 21st-century learning (OECD, 2023; Song et al., 2024). Furthermore, the empirical evidence from this study demonstrates that integrating PBL-FC with Baduy cultural wisdom can serve as a culturally responsive pedagogical model that is not only statistically significant but also practically impactful in reducing students' learning disparities.

In summary, this study offers dual contributions: (1) strengthening the literature on PBL-FC and culturally responsive pedagogy in the context of Indonesian primary education; and (2) providing an implementable framework for schools to actualize the *Profil Pelajar Pancasila* through adaptive, inclusive, and culturally grounded approaches. The novelty of this study lies in

the synergy between methodological innovation (PBL-FC) and cultural reconstruction (Baduy local wisdom), which together hold the potential to narrow achievement gaps while sustainably improving the quality of mathematics learning. Despite the promising results, this study has several limitations. First, the sample was drawn from a single elementary school, which may limit the generalizability of the findings to other educational contexts. Second, the intervention duration was relatively short, and long-term retention of critical thinking skills remains untested. Third, the Flipped Classroom component relied on students' access to digital devices and internet connectivity, which could affect equity and implementation fidelity. Fourth, the model is culturally grounded in Baduy local wisdom, and its applicability to other cultural contexts requires careful adaptation. Future research should address these limitations by including multiple schools, longer intervention periods, and comparative studies across diverse cultural settings to validate the model's effectiveness and scalability. The novelty of this study lies in the synergy between methodological innovation (PBL-FC) and cultural reconstruction (Baduy local wisdom), which together hold the potential to narrow achievement gaps while sustainably improving the quality of mathematics learning.

4. CONCLUSION

The Problem-Based Learning – Flipped Classroom (PBL-FC) model integrated with Baduy local wisdom developed in this study has been proven valid, practical, and effective in enhancing elementary students' mathematical critical thinking skills, particularly for students with low academic ability, who demonstrated the greatest improvement. Validation by experts yielded an average score of 87.5% (highly valid), while the practical implementation scores from teacher observations (97.08%) and student responses (86.16%) confirm that the model is feasible, contextually relevant, and well-received. Effectiveness analysis showed that students using the PBL-FC model achieved significantly higher critical thinking gains (N-Gain = 0.74, high category; Cohen's d = 1.21, large effect) compared to those using conventional PBL (N-Gain = 0.57, medium category), highlighting that the integration of Baduy local wisdom serves as cultural scaffolding that enhances relevance, motivation, engagement, and comprehension of mathematical concepts. ANOVA results further indicated that the model's effectiveness varies with students' academic abilities, suggesting that differentiated instructional strategies embedded within the model are essential to maximize learning outcomes.

The findings provide strong evidence that the PBL-FC model with integrated Baduy local wisdom is highly suitable for implementation within the Merdeka Curriculum framework. Specifically, it offers teachers a structured, culturally responsive, and student-centered pedagogical approach that simultaneously promotes higher-order thinking skills (HOTS), engagement, and comprehension. Teachers can adapt this model to design lessons that are not

only theoretically rigorous but also contextually meaningful, providing differentiated scaffolding tailored to students' varied ability levels. The model also establishes a replicable blueprint for embedding local culture into mathematics instruction, thereby fostering cognitive development alongside socio-cultural literacy. Additionally, the model's design supports blended learning modalities, balancing digital media utilization with offline resources to address issues of accessibility and equity, particularly in rural or under-resourced educational settings.

Future studies should critically examine the scalability and adaptability of the PBL-FC model across different educational contexts, including varied grade levels, regions, and socio-cultural settings. This includes expanding the integration of diverse local wisdom traditions to investigate the transferability of culturally contextualized mathematics learning. Researchers are encouraged to systematically explore the incorporation of a wider array of digital learning technologies, such as AI-assisted tutoring, gamified learning platforms, and mobile-based interactive modules, to enhance interactivity, accessibility, and student autonomy in flipped classroom environments. Longitudinal research is strongly recommended to assess the sustainability and retention of learning outcomes, including the long-term development of critical thinking, problem-solving skills, and other 21st-century competencies. Furthermore, future investigations could employ mixed-methods designs to explore the nuanced interplay between cultural scaffolding, motivation, engagement, and learning outcomes, providing a more comprehensive understanding of how culturally responsive pedagogy can be operationalized effectively in mathematics education.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia (*Kementerian Riset, Teknologi, dan Pendidikan Tinggi* / Kemenristekdikti) for funding support through the *Penelitian Dosen Pemula (PDP)* scheme in 2025 (125/C3/DT.05.00/PL/2025 and 8069/LL4/PG/2025).

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