

EFFECT OF THE PROBLEM-BASED LEARNING FLIPPED CLASSROOM MODEL ON JUNIOR HIGH SCHOOL STUDENTS' DIGITAL LITERACY AND CRITICAL THINKING SKILLS

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Abstrak

Literasi digital dan kemampuan berpikir kritis peserta didik yang masih rendah dalam pembelajaran matematika menjadi sorotan penting bagi pelaksanaan pembelajaran di era digital. Proses pembelajaran matematika yang tidak mengintegrasikan teknologi digital mengakibatkan kompetensi tersebut sulit dikembangkan. Penelitian ini bertujuan untuk menganalisis perbedaan kemampuan berpikir kritis dan literasi digital matematika pada siswa yang diajar dengan model Problem Based Learning Flipped Classroom (PBLFC), Problem Based Learning (PBL), dan Direct Instruction (DI), dengan mengontrol kemampuan awal siswa. Desain penelitian adalah eksperimen semu dengan analisis MANCOVA. Sampel terdiri dari 144 siswa kelas VIII SMP Negeri 1 Blahbatuh yang dibagi menjadi tiga kelompok, masing-masing 48 siswa. Instrumen berupa angket literasi digital dan tes berpikir kritis matematika telah terbukti valid dan reliabel. Hasil analisis menunjukkan bahwa secara simultan terdapat perbedaan signifikan pada kedua variabel tersebut. Untuk literasi digital, kelompok PBLFC berbeda signifikan dengan PBL dan DI, sedangkan PBL tidak berbeda signifikan dengan DI. Untuk kemampuan berpikir kritis, semua pasangan kelompok menunjukkan perbedaan signifikan. Penelitian ini menegaskan bahwa pengembangan literasi digital dan berpikir kritis memerlukan desain pembelajaran yang memadukan pemecahan masalah dengan belajar mandiri berbasis digital. Penelitian selanjutnya dapat menguji efektivitas model PBLFC di jenjang dan konteks yang berbeda.

Kata Kunci: Problem-Based Learning, Flipped Classroom; Literasi Digital; Kemampuan Berpikir Kritis

Abstract

The low level of digital literacy and critical thinking skills among students in mathematics learning has become a major concern in the implementation of digital-era education. Mathematics instruction that does not integrate digital technology hinders the development of these competencies. This study aims to analyze the differences in critical thinking skills and mathematical digital literacy among students taught using the Problem Based Learning Flipped Classroom (PBLFC) model, the Problem Based Learning (PBL) model, and the Direct Instruction (DI) model, while controlling for students' initial abilities. This study employed a quasi-experimental design with MANCOVA as the data analysis technique. The sample consisted of 144 eighth-grade students from SMP Negeri 1 Blahbatuh, divided into three groups of 48 students each. The instruments, comprising a digital literacy questionnaire and a mathematical critical thinking test, were proven to be valid and reliable. The results showed that, simultaneously, there were significant differences in both variables. In terms of digital literacy, the PBLFC group differed significantly from the PBL and DI groups, while no significant difference was found between the PBL and DI groups. In terms of critical thinking ability, all pairs of groups showed significant differences. This study confirms that developing digital literacy and critical thinking skills requires a learning design that integrates problem-solving with technology-based independent learning. Future research should examine the effectiveness of the PBLFC model across different educational levels and contexts.

Keyword: Problem-Based Learning; Flipped Classroom; Digital Literacy; Critical Thinking

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INTRODUCTION

Education serves as the primary foundation for developing intelligent, innovative, competent, and possess strong character individuals. In the digital era, perspectives on learning have changed significantly. Curriculum, learning media, and educational technology are now designed to integrate cognitive, affective, and psychomotor competencies in order to produce a generation capable of utilizing science, technology, and information effectively. Entering the twenty-first century, globalization has brought major transformations across various sectors, including education. The demands of modern life require individuals to possess competencies aligned with twenty-first-century skills, commonly referred as the 6C framework, which includes character, citizenship, critical thinking, creativity, collaboration, and communication. The rapid advancement of technology has also provided greater accessibility in various aspects of education while encouraging the development of educational technology as a field of study (Faiza & Wardhani, 2024). According to the Association for Educational Communications and Technology (AECT), educational technology is defined as the ethical study and practice of facilitating learning and improving performance through the creation, utilization, and management of appropriate technological processes and resources. Therefore, the integration of technology into learning has become a strategic necessity to support the optimal development of students' competencies (Prinanda, 2025).

The implementation of educational technology plays an important role in achieving the objectives of mathematics learning. Permendikbud (2014) states that one of the objectives of mathematics education is to train students to use reasoning, manipulate mathematical forms, and analyze components of problem-solving in the contexts of mathematics, daily life, science, and technology (Salmah et al., 2024). Teachers play a key role in implementing this technology. However, conditions in the field indicate that Indonesian students' mathematical abilities remain relatively low. PISA 2022 data recorded Indonesia's average mathematics score at only 354 points, far below the OECD average of 485 points. Only 18 percent of Indonesian students achieved Level 2 or higher in mathematical literacy, whereas the OECD average reached 69 percent. At the highest proficiency levels (Levels 5–6), fewer than 1 percent of Indonesian students achieved these levels, compared to 9 percent of OECD students on average. These findings indicate that Indonesian students' critical thinking, logical reasoning, and problem-solving abilities remain weak. Various studies have reported similar findings among junior high school students in Surakarta, Jombang, Pekanbaru, as well as in solving PISA-type mathematics problems (Jainuddin et al., 2025). Critical thinking skills are also regarded as essential competencies that must be strengthened at the junior high school level (Arimbawa et al., 2024). The low level of critical thinking is influenced by several interconnected factors. One of the primary causes is teacher-centered learning dominated by lectures and memorization, which provides limited opportunities for students to analyze, evaluate, or make independent decisions. At the same time, students' learning motivation is considered closely related to their critical thinking abilities (Linsih et al., 2025). In this context, the inappropriate selection of learning models, limited learning resources, low interest in learning, and anxiety toward difficult material also contribute to students' critical thinking problems (Santyasa et al., 2025). When students are only accustomed to low-level cognitive questions, they are not adequately trained to perform analysis, synthesis, or deeper evaluation. Furthermore, the transition to online or hybrid learning after the COVID-19 pandemic has increased the need for digital literacy, while low levels of digital literacy have also contributed to weak critical thinking abilities.

On the other hand, post-pandemic online and hybrid learning, along with students' habits of using digital technology in their daily lives, have increased the importance of mastering digital literacy. This condition is supported by the impact of the pandemic and the rapid development of digital technology, which have transformed various teaching methods, resulting in educators' and

students' digital competencies no longer being the same as before (Velandia Rodriguez et al., 2022). Studies have revealed that adequate digital literacy is essential for students to meet the demands and master innovative learning models in the future (Li & Yu, 2022). In relation to critical thinking, studies have also indicated that low digital literacy contributes to weak critical thinking skills because these two variables are interconnected and have a significant relationship within technology-based digital learning contexts (Haryanto et al., 2022). Research has further shown that digital literacy plays an important role in improving thinking skills, which directly affect academic achievement (Saputra et al., 2024). When students utilize technology to learn instructional material, they simultaneously activate digital literacy skills that require critical thinking to filter relevant information and identify appropriate information sources (Tinmaz et al., 2023). Nevertheless, the dominance of conventional learning models remains one of the factors contributing to low digital literacy (Puger et al., 2024). This finding is also supported by the researcher's observations in junior high schools, which revealed that learning activities are still dominated by teachers and provide limited opportunities for students to engage actively in learning through digital technology, thereby affecting the development of digital literacy competencies (Karimulloh et al., 2025).

To address these issues, Problem-Based Learning (PBL) can serve as an effective solution. PBL encourages students to actively solve real-world problems while developing their critical thinking skills. Previous studies have demonstrated that PBL differs significantly from conventional learning and is effective in improving junior high school students' critical thinking abilities (Meiliati et al., 2026). However, PBL also has limitations in terms of time efficiency because discussion and concept discovery processes often require considerable instructional time. Therefore, Flipped Classroom, as part of blended learning, can be integrated with PBL. In a Flipped Classroom approach, students study learning materials independently at home using digital media such as instructional videos and interactive electronic worksheets (e-LKPD), allowing classroom sessions to focus on discussion and problem-solving activities. The implementation of flipped learning has been examined in various studies, which indicate that this approach continues to develop and remains relevant for integration into different stages of instructional models (Kustandi et al., 2025). The integration of PBL and Flipped Classroom (PBLFC) enables students to learn more flexibly, solve contextual problems, and develop technological literacy (Badriyah et al., 2025; Majid & Arifin, 2025).

Although previous studies have shown that PBL and Flipped Classroom independently improve critical thinking skills as well as other variables such as learning interest, research specifically examining the integration of both approaches (PBLFC) in mathematics learning and its influence on critical thinking skills and digital literacy remains limited. Furthermore, studies utilizing interactive e-LKPD as a supporting medium for PBLFC are still relatively scarce, indicating that the potential of this medium has not been fully explored. Therefore, this study is important to address these research gaps while contributing both practically and theoretically to digital-based learning innovation. Based on the background, urgency, and research gaps that have been described, the researcher considers it necessary to conduct a study examining the effect of the PBL Flipped Classroom model on students' critical thinking skills and mathematical digital literacy among eighth-grade students at SMP Negeri 1 Blahbatuh.

METHOD

This study employed a quasi-experimental design because the researcher was unable to fully control and manipulate all variables involved in the study. A quasi-experimental approach aims to examine causal relationships by involving both control and experimental groups; however, the assignment of these groups is not conducted randomly. The study was implemented within existing classroom groups because the class structure could not be reorganized, resulting in limitations in controlling

and managing the research variables. Control over the independent variables in this study was therefore limited, meaning that not all factors potentially influencing the outcomes could be fully regulated. Accordingly, this study applied a quasi-experimental approach to examine the effect of the Problem-Based Learning model integrated with Flipped Classroom on students' digital literacy and critical thinking skills in mathematics learning. The research design employed was the Pretest–Posttest Nonequivalent Control Group Design, which was selected due to limitations in comprehensively controlling and manipulating all relevant variables. The research design scheme is presented in Figure 1. Despite the partially uncontrolled conditions, this approach still enabled the researcher to obtain a systematic overview of the treatment effects.

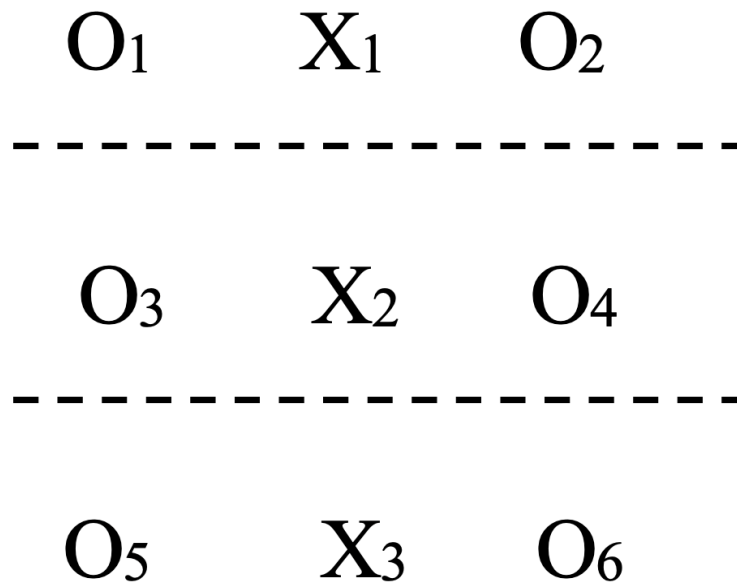


Figure 1. Research Design

The study was conducted at SMP Negeri 1 Blahbatuh through a series of systematically organized procedures, beginning from the preparation stage to the completion of the final report. All stages of the study were carried out from August 2025 to May 2026. The study involved two learning groups. The experimental groups received either PBLFC or PBL treatment, while the control group received Direct Instruction (DI). Both the experimental and control groups were provided with the same instructional materials and time allocation. Based on the research design presented in Figure 1, the PBLFC and PBL experimental groups began with a pretest (O_1 and O_3), followed by treatment implementation (X_1 for PBLFC in Class VIII B and X_2 for PBL in Class VIII C), and concluded with a posttest (O_2 and O_4). Meanwhile, the DI control group began with a pretest (O_5), received treatment X_3 (DI in Class VIII E), and ended with a posttest (O_6).

The population consisted of all eighth-grade students, with 520 students distributed across 11 classes. The sample was selected using a group random sampling technique, resulting in the selection of three classes: Experimental Group 1 (PBLFC, $n = 48$), Experimental Group 2 (PBL, $n = 48$), and the Control Group (DI, $n = 48$). The independent variable was the learning model, while the dependent variables were critical thinking skills and digital literacy, with pretest scores serving as covariates. The instruments used in this study consisted of an essay-based critical thinking test and a digital literacy questionnaire. Content validity testing using the Gregory method yielded a coefficient value of $V = 0.846$ for the questionnaire instrument and $V = 0.75$ for the test instrument. Empirical testing involving 91 students demonstrated good empirical validity (r -calculated $>$ r -table 0.206) and very high reliability (Cronbach's Alpha = 0.966 for the questionnaire and 0.816 for the

test). The test difficulty index was categorized as moderate (0.457–0.687), while the discrimination index was categorized as adequate (0.212–0.312). Data analysis was conducted descriptively by presenting measures of central tendency and data dispersion, including mean, median, and standard deviation, combined with the ideal mean approach. To describe the qualification levels of students' critical thinking and digital literacy scores, the pretest and posttest data were converted based on predetermined assessment criteria. The determination of these qualification levels was based on the ideal mean (M_i) and ideal standard deviation (SD_i), as presented in Table 1. This approach enabled more systematic and consistent data interpretation in classifying students' achievement levels (Muliarsa et al., 2024).

Table 1. Classification Criteria with Ideal Mean

Value	Category
$X > (M_i + 1,5 SD_i)$	Excellent
$(M_i + 0,5 SD_i) < X \leq (M_i + 1,5 SD_i)$	Good
$(M_i - 0,5 SD_i) < X \leq (M_i + 0,5 SD_i)$	Moderate
$(M_i - 1,5 SD_i) < X \leq (M_i - 0,5 SD_i)$	Low
$X \leq (M_i - 1,5 SD_i)$	Very Low

The analysis of the critical thinking and digital literacy pretest and posttest data was followed by hypothesis testing. Hypothesis testing began with prerequisite testing for MANCOVA at a 5% significance level using IBM SPSS Statistics. The hypothesis testing procedure employed multivariate analysis of covariance (MANCOVA) to examine differences in critical thinking skills and digital literacy both simultaneously and separately among the three subject groups.

RESULT

The research findings began with a general description of the variables of students' critical thinking skills and digital literacy, which were presented through descriptive statistical values, including categorization based on the ideal mean. For the digital literacy variable, the measurement instrument consisted of 26 items scored on a scale ranging from 1 to 5 for each item. The ideal maximum score was 130, the ideal minimum score was 26, the ideal mean was 60, and the ideal standard deviation was 17.33. The pretest and posttest results based on the ideal mean and ideal standard deviation for each learning model group are presented in Table 2.

Table 2. Descriptive Statistics of Junior High School Students' Digital Literacy Scores

No	Statistic	Group					
		DI		PBL		PBLFC	
		Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
1	Mean	86,33	87,77	92,29	90,75	100,94	104,75
2	Median	86,00	86,50	92,00	90,00	102,00	105,00
3	Maximum	100,00	110,00	104,00	110,00	116,00	115,00
4	Minimum	74,00	73,00	79,00	65,00	85,00	90,00
5	Range	26,00	37,00	25,00	45,00	31,00	25,00
6	Variant	35,47	53,63	37,62	63,10	46,10	35,06
7	Standard Deviation	6,02	7,40	6,20	8,03	6,86	5,98

In the pretest, the DI group recorded 92% of students in the excellent category and 8% in the good category, which changed after the treatment to 94% excellent and 6% good. The PBL group decreased from 100% excellent to 96% excellent and 4% good. Meanwhile, the PBLFC group consistently achieved 100% in the excellent category in both the pretest and posttest. The complete profile of students' digital literacy is presented in Table 3.

Table 3. Percentage Scores and Quality of Junior High School Students' Digital Literacy

Quality	Group					
	DI		PBL		PBLFC	
	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
Excellent	92%	94%	100%	96%	100%	100%
Good	8%	6%	0%	4%	0%	0%
Moderate	0%	0%	0%	0%	0%	0%
Low	0%	0%	0%	0%	0%	0%
Very Low	0%	0%	0%	0%	0%	0%

The mean score of the DI group increased from 86.33 to 87.77, while the standard deviation increased from 6.02 to 7.40. The PBL group decreased from 92.29 to 90.75, with the standard deviation increasing from 6.20 to 8.03. In contrast, the PBLFC group increased from 100.94 to 104.75, while the standard deviation decreased from 6.86 to 5.98. The highest maximum score was recorded in the PBLFC pretest group (116.00), whereas the lowest minimum score was found in the PBL posttest group (65.00). The widest score range was also observed in the PBL posttest group (45.00). The highest mean improvement was achieved by the PBLFC group (3.81 points), followed by the DI group (1.44 points), while the PBL group experienced a decline of 1.54 points. The standard deviations of the DI and PBL groups increased, indicating less evenly distributed outcomes, whereas the standard deviation of the PBLFC group decreased, reflecting more consistent results among students. The median score of the PBLFC group increased from 102.00 to 105.00, while the median score of the PBL group declined from 92.00 to 90.00. These findings indicate that the PBLFC model was the most effective because it not only increased the average score but also reduced the achievement gap among students. The quality of the critical thinking pretest and posttest analysis based on the ideal mean and ideal standard deviation of each learning model group is presented in Table 4.

Table 4. Percentage Scores and Quality of Critical Thinking Skills of Middle School Students

Quality	Group					
	DI		PBL		PBLFC	
	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
Excellent	0%	6%	0%	48%	6%	73%
Good	2%	60%	19%	46%	54%	27%
Moderate	17%	33%	50%	6%	31%	0%
Low	54%	0%	29%	0%	8%	0%
Very Low	27%	0%	2%	0%	0%	0%

In the critical thinking pretest, the DI group was dominated by the low category (54%) and very low category (27%). The PBL group was dominated by the moderate category (50%) and low category (29%). Meanwhile, the PBLFC group demonstrated better initial conditions, with the majority of students categorized as good (54%) and moderate (31%), while 6% had already reached the excellent category. In the posttest, the DI group no longer contained students in the low or very low categories, shifting instead to good (60%), moderate (33%), and excellent (6%). The PBL group improved to 48% excellent and 46% good, although a small proportion of students still remained in the low and very low categories. The PBLFC group demonstrated the most substantial improvement, with 73% categorized as excellent and 27% as good, without any students remaining in the moderate, low, or very low categories. These findings indicate that the PBLFC model was the most effective because it improved both the quality and distribution of students' learning outcomes. The complete profile of critical thinking skills is presented in Table 5.

Table 5. Descriptive Statistics Critical Thinking Skill Scores of Junior High School Students

No	Statistic	Group					
		DI		PBL		PBLFC	
		Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
1	Mean	13,08	24,98	18,52	29,98	24,31	32,73
2	Median	13,00	25,00	18,00	30,00	25,00	33,00
3	Maximum	24,00	32,00	30,00	36,00	37,00	40,00
4	Minimum	4,00	18,00	7,00	22,00	12,00	26,00
5	Range	20,00	14,00	23,00	14,00	25,00	14,00
6	Standard Deviation	20,28	12,81	21,79	13,69	25,38	11,45

Based on Table 5, the DI group improved in terms of mean score from 13.08 to 24.98, median from 13.00 to 25.00, maximum score from 24.00 to 32.00, minimum score from 4.00 to 18.00, while the range decreased from 20.00 to 14.00. The PBL group improved in mean score from 18.52 to 29.98, median from 18.00 to 30.00, maximum score from 30.00 to 36.00, minimum score from 7.00 to 22.00, and the range decreased from 23.00 to 14.00. The PBLFC group improved in mean score from 24.31 to 32.73, median from 25.00 to 33.00, maximum score from 37.00 to 40.00, minimum score from 12.00 to 26.00, and the range decreased from 25.00 to 14.00. All groups experienced a decrease in standard deviation, indicating more evenly distributed results. The magnitude of the mean score improvement was 11.90 points for DI, 11.46 points for PBL, and 8.42 points for PBLFC. Although the increase in the PBLFC group was the smallest, its final achievement remained the highest (32.73) because the group had already demonstrated higher initial ability. Therefore, the PBLFC model produced the most optimal outcomes for critical thinking skills. The MANCOVA prerequisite tests conducted at a 5% significance level using IBM SPSS Statistics indicated that all assumptions were fulfilled. The Kolmogorov–Smirnov normality test produced significance values greater than 0.05 for all datasets, indicating that the data were normally distributed. The Box's M test (Sig. = 0.599) and Levene's tests (Sig. = 0.591; 0.394; 0.829; 0.807) also produced values greater than 0.05, indicating that the covariance matrices and variances across groups were homogeneous. The linearity test produced significance values of 0.490 for digital literacy and 0.962 for critical thinking, both greater than 0.05, indicating linear relationships between pretest and posttest scores. The regression significance test produced values below 0.001, indicating that students' initial critical thinking skills and digital literacy significantly influenced the final outcomes. The collinearity test showed correlations among dependent variables ranging from 0.399 to 0.472, all below 0.80, indicating the absence of high collinearity. Multivariate MANCOVA analysis was then conducted to determine simultaneous differences in digital literacy and critical thinking among the PBLFC, PBL, and DI groups while controlling for covariate variables. The results are presented in Table 6.

Table 6. Multivariate Test Results

		Multivariate Test		
Effect		Value	F	Sig.
Learning model	Pillai's Trace	0,383	16,473	<0,001
	Wilks' Lambda	0,643	17,072	<0,001
	Hotelling's Trace	0,516	17,667	<0,001
	Roy's Largest Root	0,420	29,190	<0,001

The multivariate test results presented in Table 6 show that all significance values for Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root were below 0.001. The Wilks' Lambda value was 0.643 with an F-value of 17.072. Since the significance value was below 0.05, there were significant simultaneous differences in digital literacy and critical thinking among the PBLFC, PBL, and DI groups. Thus, the learning models collectively influenced both dependent variables, and the multivariate hypothesis was accepted. Furthermore, univariate tests were

conducted to examine the influence of the learning models on digital literacy and critical thinking separately. The results of the Tests of Between-Subjects Effects are presented in Table 7.

Table 7. Univariate Test Results

Univariate Hypothesis Test			
	<i>Dependent Variable</i>	<i>F</i>	<i>Sig.</i>
Learning model	Digital Literacy Post-Test	17,677	<0,001
	Critical Thinking Post-Test	19,725	<0,001

The univariate test results presented in Table 7 indicate that the digital literacy variable obtained an F-value of 17.677 with a significance value below 0.001. Since the significance value was below 0.05, H₀ was rejected. This finding indicates that differences in digital literacy existed among the PBLFC, PBL, and DI groups after controlling for initial ability. For the critical thinking variable, the F-value was 19.725 with a significance value below 0.001. Since the significance value was below 0.05, H₀ was also rejected. This indicates that significant differences in critical thinking skills existed among the three groups after controlling for initial ability. Therefore, the PBLFC model produced more optimal outcomes than the PBL and DI models for both variables. A follow-up pairwise comparison test with Bonferroni adjustment was conducted to identify differences among group pairs in terms of digital literacy and critical thinking. The results are presented in Table 8.

Table 8. Results of the Advanced Pairwise Comparisons Test

Pairwise Comparisons				
Dependent Variable	(I) Model	(J) Model	Mean Difference (I-J)	Sig
Digital Literacy Post-Test	DI	PBL	-0,160	1,000
		PBLFC	-9,854	<0,001
	PBL	DI	0,160	1,000
		PBLFC	-9,694	<0,001
	PBLFC	DI	9,854	<0,001
		PBL	9,694	<0,001
Critical Thinking Skills Post-Test	DI	PBL	-4,200	<0,001
		PBLFC	-8,195	<0,001
	PBL	DI	4,200	<0,001
		PBLFC	-3,995	<0,001
	PBLFC	DI	8,195	<0,001
		PBL	3,995	<0,001

The follow-up test results for digital literacy indicate no significant difference between the DI and PBL groups (Sig. = 1.000). However, the PBLFC group achieved significantly higher scores than the DI group (difference = 9.854, Sig. < 0.001) and the PBL group (difference = 9.694, Sig. < 0.001). For critical thinking skills, all group pairs differed significantly (Sig. < 0.001). The PBL group scored higher than the DI group (difference = 4.200), the PBLFC group scored higher than the DI group (difference = 8.195), and the PBLFC group scored higher than the PBL group (difference = 3.995). Therefore, the PBLFC model can be regarded as the most effective model for fostering students' digital literacy and critical thinking skills.

DISCUSSION

The multivariate test results indicate that the learning model had a significant simultaneous effect on digital literacy and critical thinking skills. The PBLFC model proved to be the most effective compared with PBL and DI because it integrated problem-solving activities with digital learning through the flipped classroom approach. This integration created more meaningful learning experiences, enabling students to access, evaluate, and utilize digital information while simultaneously developing higher-order thinking skills. The strength of PBLFC lies in its characteristics, which position students at the center of the learning process and provide opportunities for exploration before and during classroom instruction. In the PBLFC class, students

participated in the before-class stage through online learning activities, allowing them to be better prepared during face-to-face sessions. Students actively engaged in discussions, asked questions, and solved geometry problems. During the after-class stage, students conducted independent reflection through digital media, which reinforced their understanding and confidence in using technology. In contrast, the PBL class remained primarily focused on classroom-based learning without structured preparation, resulting in less optimal information exploration (Kusnandar et al., 2025). Meanwhile, the DI class tended to be more passive, with limited technology utilization. Therefore, digital literacy should not only be understood as the ability to operate devices but also as the ability to utilize technology to search for, select, and process information. These findings are consistent with previous studies indicating that blended learning effectively develops critical thinking skills by combining independent learning and classroom instruction (Nugraha, 2020). Other studies have also demonstrated that digital literacy improves through the intensity of students' digital activities (Lan et al., 2026). Furthermore, problem-based learning integrated with inquiry activities has been shown to enhance critical thinking skills (Asy'ari, 2026). Thus, this study reinforces the argument that integrating PBL with the flipped classroom approach is more effective in simultaneously developing both competencies. The development of critical thinking skills and digital literacy requires learning designs that integrate technology meaningfully rather than merely using it as a supporting tool. Learning activities should gradually develop digital literacy, ranging from basic competencies to the use of digital technology for transformative learning purposes (Wahyuni et al., 2025). Technology becomes more effective when incorporated into interactive activities such as exploration, discussion, and problem-solving. Therefore, successful learning in the digital era is strongly influenced by the selection of learning models and approaches that are relevant to students' needs.

The test results also showed that the learning model had a significant effect on digital literacy ($F = 17.677$; $\text{Sig.} < 0.001$). The PBLFC group differed significantly from the DI group (difference = 9.854) and the PBL group (difference = 9.694), whereas no significant difference was found between the PBL and DI groups. These findings indicate that improvements in digital literacy only occurred significantly within the PBLFC group. The PBLFC model integrated problem-based learning with digital technology, allowing digital literacy to develop through students' active involvement in accessing, processing, and utilizing digital information in authentic contexts.

In the PBLFC class, students participated in the before-class stage using digital platforms such as WhatsApp, Google Classroom, and GeoGebra. Students became accustomed to searching for information before the class session began. During the in-class stage, students demonstrated greater confidence in discussions and problem-solving activities. In the after-class stage, students reflected through digital media. By contrast, the PBL class remained limited to the use of printed worksheets, resulting in less optimal digital literacy development. Meanwhile, the DI class was dominated by teacher-centered instruction with minimal technology utilization, as smartphones were considered distractions to students' learning focus. These findings are consistent with several previous studies. Research has shown that flipped classroom learning supported by relevant digital tools and guided by teachers in concept discovery can improve students' motivation and the quality of technology utilization (Sari et al., 2025). These findings are further supported by studies emphasizing that implementing flipped classroom within a meaningful learning framework significantly improves digital literacy (Paristiowati et al., 2025). Other studies also indicate that the flipped classroom model, which combines online and face-to-face learning, effectively enhances digital literacy while improving instructional practices (Molina-Torres, 2024). Therefore, this study not only supports but also strengthens empirical evidence that integrating problem-based learning with flipped classroom produces a greater impact on digital literacy compared with standalone PBL or DI models. From a

practical perspective, these findings emphasize that developing students' digital literacy requires more than merely providing technological devices. Effective instructional strategies are needed to integrate technology meaningfully into learning activities. Digital literacy should be developed as a dual competency involving both technical skills and cognitive competencies, enabling students to critically select, evaluate, and utilize information within problem-solving contexts (Adzra et al., 2025). The success of PBLFC in this study also demonstrates that students' backgrounds, learning experiences, and curriculum design contribute to digital literacy achievement. Therefore, strengthening digital literacy requires systemic support, including technological infrastructure, teacher training in designing digital-based instruction, and adaptive learning designs aligned with technological developments. Consequently, the PBLFC model proved to be a relevant and effective strategy for significantly developing students' digital literacy while also serving as a foundation for educational policy and instructional practice in the digital era.

The test results further revealed that the learning model had a significant effect on critical thinking skills ($F = 19.725$; $\text{Sig.} < 0.001$). Significant differences were found among all group pairs, with the highest performance demonstrated by the PBLFC group, followed by the PBL group, and the lowest by the DI group. These findings indicate that students' critical thinking skills developed in accordance with the characteristics of the implemented learning model. The superiority of PBLFC lies in its integration of problem-solving activities with technology-based learning before classroom instruction begins. In the PBLFC class, students participated in the before-class stage by independently preparing learning materials through digital platforms such as Google Classroom and GeoGebra. These activities included reviewing learning objectives, preparing learning materials, and independently completing worksheets. As a result, students entered face-to-face sessions with prior preparation rather than starting from the beginning. They were more prepared to engage in discussions, analyze problems, evaluate solution strategies, and draw conclusions more deeply (Meiliati et al., 2026; Moundy et al., 2022). During the after-class stage, students conducted reflection and evaluation activities online, allowing the thinking process to continue beyond classroom instruction and develop continuously. In contrast, students in the PBL class also demonstrated active participation in discussions and problem-solving activities, such as understanding contextual problems and collaborating in groups. However, these activities remained limited to classroom learning sessions without structured preparation beforehand (Awaluddin et al., 2023; Badriyah et al., 2025). Consequently, the processes of analysis and information exploration did not develop optimally. Meanwhile, the DI class was dominated by teacher lectures and note-taking activities. Students mainly listened to explanations and completed exercises individually. Although they were still able to complete assigned tasks, their involvement in deeper analytical processes remained limited, preventing critical thinking skills from developing optimally. These findings are consistent with previous studies showing that the combination of PBL and flipped classroom improves conceptual understanding and critical thinking skills (Domu et al., 2023). Other studies also emphasize that flipped classroom transforms students' roles into more active and independent learners in analysis, argumentation, and conclusion drawing (Wijayanto et al., 2023). Therefore, this study strengthens empirical evidence that the effectiveness of flipped classroom becomes more optimal when combined with a problem-based approach.

The development of critical thinking skills in mathematics learning should be designed through strategies that continuously encourage students' active participation. Teachers should not merely present learning materials and assign exercises. Instead, teachers need to design learning activities that encourage discussion, argumentation, and contextual problem-solving relevant to students' daily lives (Husna et al., 2025). Furthermore, technology utilization should be integrated meaningfully rather than functioning solely as a supporting tool. Therefore, the integration of PBL

with flipped classroom has proven effective in developing students' critical thinking skills while also serving as an example of mathematics instruction that aligns with the demands of twenty-first-century learning.

CONCLUSION

This study concluded that the PBLFC model was the most effective compared to PBL and DI in simultaneously improving students' digital literacy and critical thinking skills. In terms of digital literacy, PBLFC showed significant differences compared to the other two models, whereas no significant difference was found between PBL and DI. Regarding critical thinking skills, all three groups demonstrated significant differences, with PBLFC achieving the highest outcomes, followed by PBL and DI. As an implication, teachers are recommended to implement PBLFC by utilizing digital platforms such as Google Classroom and GeoGebra, while preparing students before, during, and after the learning process. Schools are also encouraged to provide adequate technological infrastructure and continuous teacher training. Future researchers are advised to examine other variables, such as learning motivation or self-efficacy, and to expand the scope of research to different educational levels or subject areas.

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