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The Influence of Mathematical Problem-Solving and Critical Thinking Skills through Project-Based Flipped Classroom and Self-Regulated Learning

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Abstract:

Introduction: In the field of mathematical education, enhancing problem-solving and critical thinking skills is essential for students to tackle complex mathematical challenges.

Objectives: This study investigates the impact of Project-Based Flipped Classroom (PBFC) and Self-Regulated Learning (SRL) on improving these cognitive abilities within mathematics. A 2 x 2 factorial design with a nonequivalent control group pretest-posttest design was used to evaluate the effects.

Methods: The participants included 64 seventh-grade students from SMP Negeri 2 Kedungpring Lamongan, divided into two groups using cluster random sampling. Data were collected through mathematical problem-solving tests and SRL-related questionnaires, with analysis performed using MANOVA.

Results: The results revealed that (1) PBFC positively influenced students' mathematical problem-solving and critical thinking skills, (2) SRL contributed significantly to the improvement of these skills, (3) the interaction between PBFC and SRL enhanced both problem-solving and critical thinking outcomes in mathematics, and (4) students who exhibited high SRL and participated in PBFC demonstrated better performance in mathematical tasks.

Conclusions: These findings highlight the effectiveness of integrating PBFC and fostering SRL to improve essential mathematical cognitive skills, with implications for teaching practices in mathematical education.

Keywords: critical thinking, education, flipped classroom, mathematical, problem-solving, project-based, self-regulated learning.

1. Introduction

The utilization of technology plays an important role in improving and transforming education, with the current environment being an important factor in encouraging the integration of new technologies

in the education system for its improvement and transformation (Wang et al., 2024). The teaching and learning process in the 21st century has undergone many changes and will certainly be a challenge for educators to produce highly dedicated learners as a specific response to modernization (Ismail et al., 2021). More precisely, they are ready to implement technological advances in education and learning activities. Technological developments have led to significant changes in the teaching and learning process (Ismail et al., 2021). Despite this, challenges in creating an effective and engaging learning environment remain(Johnson et al., 2024). Traditional approaches to learning are often limited to the delivery of information by the teacher in the classroom, with little room for exploration, deep student engagement or practical application of the concepts learned (Syafi'i et al., 2024).

The 21st century has many demands on it in which human resources must have creative thinking, problem solving, good communication and collaboration skills and most importantly critical thinking (Ninghardjanti & Dirgatama, 2021). Critical thinking is one of the important characters or aspects that must be formed for students and is a demanding skill in the 21st century (Agviolita et al., 2022). To strengthen the character of the Pancasila student profile, it is directed at project learning rather than one-way lectures (Anggraena et al., 2022). Project Based Learning is one of the learning models that can be used as an interesting alternative to the learning approach referred to in the project as well as the exploration of student content in collaborative experiments (Belwal et al., 2020). Project-based learning is widely recognized as an effective pedagogy to motivate and engage students (Zhong & Lyu, 2022). With the ideal conditions that occur, critical thinking skills and problem solving skills, which are the core points of society's needs, should be formed and built easily in schools.

But this ideal condition is inversely proportional to the real conditions that occur in one of the Junior High Schools in Lamongan. Based on a preliminary study through initial observations at SMP Negeri 2 Kedungpring Lampongan, what happened at the school was not the case. In the 21st century, which is all focused on improving students' critical thinking and problem-solving skills that should be of global standard, the school is very low. Especially in class VII not only lies in these two aspects but also Self-Regulated Learning which is classified as low. With this alarming condition at SMP Negeri 2 Kedungpring Lamongan, there needs to be an effort in improving their critical thinking, problem solving and self-regulated learning skills to prepare themselves for a more complex life in the future. One of the learning models that builds critical thinking and problem solving skills is Project Based Learning (PJBL).

Not only on critical thinking skills, but PJBL is also authorized in the support of students' problem solving skills. Proven by research conducted by (Karan & Brown, 2022). According to (Jaenudin et al., 2020) Project-based learning provides students with learning experiences that start with real, factual problems. On the other hand, the flipped classroom approach has gained significant popularity in recent years(Sholeh et al., 2024). Flipped classroom is one of the alternatives in online learning that can support students' problem solving skills in learning (Rahayu et al., 2022). Findings from the research (Santosa et al., 2023) proved that flipped classroom can provide high effectiveness on problem solving skills. In addition, the implementation of flipped classroom as an alternative or main strategy to improve students' problem solving in learning (Santosa et al., 2023).

However, both approaches have their own strengths and weaknesses, and there is still room for further development in practice. The combination of Project Based Learaning and Flipped Classroom,

hereafter referred to as Project Based Flipped Classroom (PBFC), promises a holistic learning approach that combines the advantages of both methods. Some other studies that have been conducted only reveal the impact of project-based learning in isolation with flipped classrooms on critical thinking skills. The supporting factors have not been examined. Therefore, it is important that this research is conducted as a first step in the future to open up opportunities and great potential as a key in rapidly improving critical thinking and problem solving skills by analyzing PBFC and Self-Regulated Learning as supporting factors.

2. Methods

2.1. Research Design and Subjects

This study is a nonequivalent pretest posstest control group (Creswell & Creswell, 2018) Factorial design is a design with more than one independent variable (or factor) (Cozby & Bates, 2012). The factorial design generates two types of information, the first is information about the effect of each independent variable and the second type of information is the interaction (Cozby & Bates, 2012). In this research, there are two groups, namely the experimental group which will be carried out learning activities using Project Based Flipped Classroom (PBFC) and the control group without using PBFC. Both groups were given a pretest to determine the initial ability of critical thinking and problem solving. Furthermore, learning activities were carried out and given a post-test at the end of learning.

Table 1: Factorial research design

SRL (B)	PBFC (A_1)		Non-PBFC (A_2)	
	CT (1)	PS (2)	CT (1)	PS (2)
High (B_1)	$A_1.1.B_1$	$A_1.2.B_1$	$A_2.1.B_1$	$A_2.2.B_1$
Low (B_2)	$A_1.1.B_2$	$A_1.2.B_2$	$A_2.1.B_2$	$A_2.2.B_2$

Source: Prepared by the author (2025)

Table 1 is a factorial research design including two learning activities carried out, namely Project Based Flipped Classroom (PBFC) and ordinary learning without using PBFC. There are two ability outcomes namely critical thinking ability (CT) and problem solving ability (PS). There are two levels of Self-regulated Lerning (SRL) in this study including low SRL and high SRL. Figure 1. is a chart of factorial research design. Students' abilities that will be analyzed from this research include (1) critical thinking ability and problem solving ability of students who follow learning using PBFC and have high SRL and low SRL; (2) critical thinking ability and problem solving ability of students who follow Non-PBFC learning and have high SRL and low SRL.

The subjects of this study were students from one of the schools in Indonesia, namely State Junior High School 2 Kedungpring in Lamongan City. The research subjects were 64 seventh grade students whose average age was 13-14 years old. The research subjects were divided into two groups, namely the experimental group of 32 students and the control group of 32 students. The sampling technique in this study used cluster random sampling (Fraenkel et al., 2012). The cluster random sampling technique was used with the consideration that it was impossible for this research to be carried out with random or threshold techniques, by taking classes that had homogeneous abilities in the implementation of learning (Cohen et al., 2007).

2.2. Research Instruments

This research instrument uses a questionnaire to measure SRL and uses tests to measure critical thinking and problem solving skills. The instrument to measure SRL consisted of 10 statement items as an adaptation of the scale developed by the researchers (Marchis & Balogh, 2010) which explains that there are four important components including (1) students' interest consists of 3 indicators; (2) self efficacy consists of 2 indicators; (3) self judgment consists of 3 indicators; and (4) self-reaction consists of 2 indicators. The instrument used to measure critical thinking ability refers to critical thinking indicators including (1) providing simple explanations; (2) building basic skills; (3) concluding; (4) providing further explanations; and (5) organizing strategies and techniques (Ennis, 1996). The instrument used to measure problem solving refers to Wena's indicators including (1) problem identification; (2) defining the problem; (3) finding a solution; (4) implementing the strategy; and (5) reviewing and evaluating the effect (Wena, 2009).

The assessment of the questionnaire instrument uses a Likert scale of 1 - 4 with criteria (1 = not suitable, 2 = less suitable, 3 = suitable, 4 very suitable). The SRL instrument has been tested for construct validity by two experts with an overall score of 97.5% including in the feasible category. Content validity testing was carried out on test instrument items with an r-table of .361. The critical thinking instrument has been tested for content validity and obtained a validity value of .520 and a reliability value of .345. The problem solving instrument has been tested for content validity and obtained a validity value of .549 and a reliability value of .425. The results of the content validity of the test instruments to measure critical thinking and problem solving skills are valid and reliable. Thus the instrument can be used in research activities.

2.3. Data Analysis

Data analysis in this study used analysis of variance or MANOVA. MANOVA is a generalization of the ANOVA test for situations where there are several dependent variables (Tabachnick & Fidell, 2007). The rationale for using MANOVA data analysis is because it can detect and reveal differences that ANOVA-ANOVA does not show on each dependent variable separately (Sutrisno & Wulandari, 2018). The basis for decision making in this MANOVA test is if the significance value> 0.05 then there is no influence between the independent variable on the dependent variable, otherwise if the significance value <0.05 then there is an influence between the independent variable on the dependent variable. For the MANOVA test, researchers used the IBM SPSS 24 Statistics For Windows application.

3. Results

3.1. Analysis of Students' Initial Ability

After the research was conducted and the pretest score data was obtained, it was analyzed first. The purpose of the analysis is to determine the initial critical thinking ability and initial problem solving ability of the students. Prerequisite testing first on normality test and homogeneity test for the next different test. The normality test of critical thinking skills shown in table 1. in the experimental class obtained Sig .141 and the control class obtained Sig .200. The normality test of problem solving ability shown in table 3. in the experimental class obtained Sig .200 and the control class obtained Sig .200. Overall the value data obtained is normally distributed. Based on the homogeneity test results in table

3. Shows that all initial ability value data are homogeneous with the acquisition of Sig on critical thinking ability value data .979 and problem solving ability value data .922.

Table 2: Normality test results of initial critical thinking skills

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
CT	PBFC	.136	32	.141	.935	32	.053
	Non-BFC	.115	32	.200*	.952	32	.166

Source: Prepared by the author (2025)

Table 3: Normality test results of initial problem solving ability

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
PS	PBFC	.112	32	.200*	.968	32	.455
	Non-BFC	.123	32	.200*	.963	32	.326

Source: Prepared by the author (2025)

Table 4: Homogeneity test results of preliminary ability score data

	Levene Statistic	df1	df2	Sig.
CT	.001	1	62	.979
PS	.010	1	62	.922

Source: Prepared by the author (2025)

Table 5: Data on preliminary critical thinking and problem solving skills

	Group	N	Mean	SD
Critical Thinking	Experiment	32	32.66	12.047
	Control	32	33.28	12.089
Problem Solving	Experiment	32	29.53	10.109
	Control	32	30.31	10.313

Source: Prepared by the author (2025)

Table 6: T-test of the preliminary critical thinking and problem solving skills

t-test of equality of means						
	F	Sig.	t	df	p	MD
Critical Thinking	.001	.979	-.207	62	.837	-.625
			-.207	61.999	.837	-.625
Problem Solving	.010	.922	-.306	62	.761	-.781
			-.306	61.975	.761	-.781

Source: Prepared by the author (2025)

Based on the results of data analysis of students' initial ability scores in table 5, it shows that the mean critical thinking ability of experimental class students is 32.66 and in the control class is 33.28. The mean acquisition of students' problem solving ability in the experimental class was 29.53 and in the control class was 30.31. Based on the results of the t-test, there is no difference in the value of critical

thinking ability with the acquisition of a p value of .837. While the initial problem solving ability obtained by students showed no difference in the value of the two classes with a p value of .761. Thus the initial critical thinking ability and initial problem solving ability of students before being treated are all the same, both in the experimental and control classes.

3.1.1. Analysis of the Effect of Project Based Flipped Classroom and Self-Regulated Learning on Critical Thinking and Problem-Solving Skills

After the initial ability is known and continued by conducting learning activities where the experimental class uses PBFC and the control class is carried out ordinary learning activities without PBFC. After the learning activities were carried out and all value data had been collected, then data analysis was carried out using MANOVA. Previously, the data had been tested for prerequisites including normality and homogeneity tests. All data values were normally distributed and homogeneous.

Tabel 7: Test of between-subjects effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	CT	3692.478[a]	3	1230.826	11.988	.000
	PS	2965.498[b]	3	988.499	12.687	.000
Intercept	CT	375337.473	1	375337.473	3655.732	.000
	PS	343470.450	1	343470.450	4408.425	.000
Group	CT	556.700	1	556.700	5.422	.023
	PS	586.975	1	586.975	7.534	.008
SRL_Level	CT	1174.337	1	1174.337	11.438	.001
	PS	914.995	1	914.995	11.744	.001
Group * SRL_Level	CT	1216.392	1	1216.392	11.847	.001
	PS	799.317	1	799.317	10.259	.002
Error	CT	6160.256	60	102.671		
	PS	4674.737	60	77.912		
Total	CT	436425.000	64			
	PS	395925.000	64			
Corrected Total	CT	9852.734	63			
	PS	7640.234	63			

Source: Prepared by the author (2025)

Tabel 8: Estimated marginal means of learning models

Dependent Variable	Group	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Critical Thinking	PBFC	83.023	1.932	79.158	86.888
	Non-PBFC	76.865	1.805	73.254	80.476
Poblem Solving	PBFC	79.636	1.683	76.269	83.003
	Non-PBFC	73.313	1.573	70.168	76.459

Source: Prepared by the author (2025)

Table 8 is the result of learning model analysis on critical thinking ability and problem solving ability. Based on the analysis, it shows that students who do learning activities using PBFC get a mean of 83.023. While in the class without using PBFC, the mean of critical thinking ability is 76.865. The group of students who did learning activities using PBFC was better in achieving critical thinking ability. For problem solving ability, students who follow learning activities using PBFC get a mean value of 79.636. While students with learning without PBFC obtained mean value 73.313. Just like critical thinking ability, where problem solving ability is better achieved by students who follow learning activities using PBFC.

Tabel 9: Estimated marginal means of self-regulated learning

Dependent Variable	SRL Level	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Critical Thinking	High	84.416	1.732	80.951	87.880
	Low	75.472	1.998	71.475	79.469
Poblem Solving	High	80.422	1.509	77.404	83.440
	Low	72.528	1.741	69.046	76.010

Source: Prepared by the author (2025)

Table 9 is the result of the analysis of SRL on critical thinking ability and problem solving ability. Based on the analysis, the mean value of critical thinking ability of students with high SRL is 84.416. While students with high SRL mean value of critical thinking ability is 75.472. Based on this data, students with high SRL tend to have better critical thinking skills. While students with low SRL tend to have critical thinking skills that are not better than high SRL. Problem solving ability of students with high SRL obtained a mean value of 80.422. While students with low SRL obtained a mean value of problem solving ability of 72.528. From these results, it can be seen that students with higher SRL tend to be better at problem solving than students with low SRL.

Tabel 10: Estimated marginal means of learning strategy and self-regulated learning

Dependent Variable	Group	SRL Level	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Critical Thinking	PBFC	High	92.045	2.160	87.724	96.367
		Low	74.000	3.204	67.591	80.409
	Non-PBFC	High	76.786	2.708	71.369	82.203
		Low	76.944	2.388	72.167	81.722
Poblem Solving	PBFC	High	87.273	1.882	83.508	91.037
		Low	72.000	2.791	66.417	77.583
	Non-PBFC	High	73.571	2.359	68.853	78.290
		Low	73.056	2.080	68.894	77.217

Source: Prepared by the author (2025)

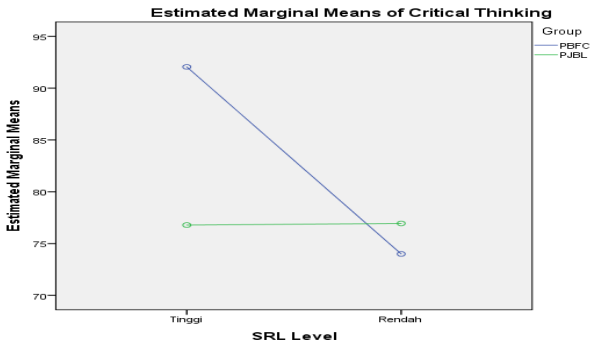

Figure 1: Interaction graph of PBFC and SRL on critical thinking skills

Table 10 shows the analysis result of learning strategy and SRL on critical thinking ability and problem solving ability. Critical thinking skills of students with low SRL who did learning activities using PBFC obtained a mean value of 92.045. Meanwhile, students with high SRL who were taught without PBFC obtained a mean value of critical thinking skills of 76.786. This result shows that students with equally high SRL obtained mean value of critical thinking skill which is different between PBFC class and class without PBFC. From these results, it can be seen that students with high SRL are much more critical thinking skills after learning using PBFC.

However, the critical thinking ability of students with low SLR obtained a slightly higher mean value in the class without PBFC. The acquisition in PBFC class mean value of critical thinking ability is 74 and the acquisition in class without PBF is 76.944. Based on the test of between-subjects effects of PBFC and SRL on critical thinking ability in table 7, Sig. .001 < .050. So there is a difference in value, so that PBFC and SRL affect the critical thinking ability. It means that students with high SRL are more compatible using PBFC to achieve better critical thinking ability. Figure 1 shows the interaction of PBFC and SRL on critical thinking ability. The interaction can be seen because of the line cut shown by the graph.

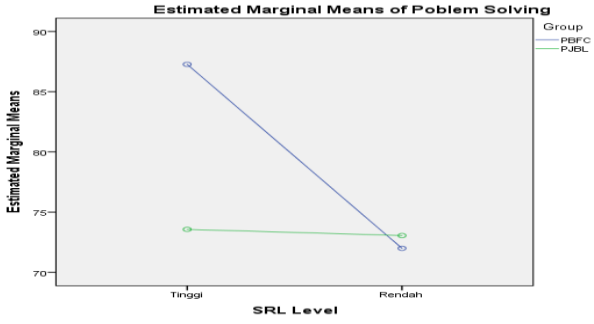

Figure 2: Interaction graph of PBFC and SRL on problem solving ability

Table 10 shows the result of PBFC and SRL analysis on problem solving ability with the mean value of 87.273 for students who were taught using PBFC with high SRL. While students who have low SRL obtained a mean value of problem solving ability of 72. The group of students who conducted learning activities without using PBFC with high SRL obtained a mean value of problem solving 73.571. While students with low SRL in the group obtained a mean value of 73.056. From these results, it can be known that students who are conducted learning activities using PBFC and have high SRL are better in achieving critical thinking skills than students who have low SRL.

When viewed in Non-PBFC class and students who have high SRL have the mean value of problem solving ability which is almost the same as students with low SRL. Based on the test of between-subjects effects in table 7, PBFC and SRL on problem solving ability obtained Sig. .002 < .050. So that from these results PBFC and SRL affect the problem solving ability. From the test result, it can be known that students with high SRL are more compatible in following learning activities using PBFC in achieving better problem solving ability. Figure 2 shows the interaction between PBFL and SRL on problem solving ability. The interaction can be seen because of the line cut shown by the graph.

4. Discussion

This research is conducted by applying PBFC learning and linking SRL factors to the achievement of critical thinking skills and problem solving skills of students. In this case, it is very important that the SRL factor is traced to find out its impact on students' ability to solve a problem with critical thinking needed through Project Based Flipped Classroom (PBFC). From the results of the initial study which indicated that students' critical thinking and problem solving skills were still relatively low. Researchers sought to provide better learning services and facilities using a learning model that could have a positive impact on critical thinking and problem solving skills. The effort was made by giving students learning using PBFC.

This study used a control group pretest postes design by giving a test at the beginning before they were given treatment. The results of the pretest in both experimental and control classes to measure critical thinking ability and initial problem solving ability. The pretest results showed the acquisition of the average value of critical thinking skills in the experimental class 32.66 and the control class 33.28. While the problem solving ability in the experimental class obtained an average value of 29.53 and the acquisition of the average value of problem solving in the control class 30.31. Based on the results of the t-test, there is no difference between the value of critical thinking skills in the experimental and control classes. And there is no difference in the value of students' problem solving skills in the experimental and control classes. From the analysis of the data that has been obtained shows that the initial ability of students is the same, and all values are still classified as low both in critical thinking skills and problem solving skills.

The research continued by applying learning to students. In the experimental class students were given learning by using PBFC, and in the control class students were carried out learning activities without using PBFC. Both followed the learning activities for 6 meetings. Learning activities using PBFC include (1) The first phase students learn independently at home online about the material for the next meeting; (2) The second phase students come to school to carry out learning activities and explore tasks in groups through projects; (3) The third phase students start projects and simulations in the classroom by doing group collaboration; (4) The fourth phase is carried out reflection and guidance; (5) The fifth phase of project completion and presentation; (6) The sixth phase is carried out evaluation activities and final reflection.

After the learning activities at the end of the meeting students were given a post-test to measure their critical thinking skills and problem solving skills. There are some findings of this research that can be analyzed. The results of data analysis that have been collected include (1) Analysis of PBFC on critical thinking ability; (2) Analysis of PBFC on problem solving ability; (3) Analysis of Self-regulated

Learning on critical thinking ability; (4) Analysis of Self-regulated problem solving ability; (5) Effect and Interaction of PBFC and Self-regulated Learning on critical thinking ability; and (6) Effect and Interaction of PBFC and Self-regulated Learning on problem solving ability.

The results of the first analysis related to PBFC on critical thinking skills obtained data that students who follow learning activities using PBFC get better critical thinking skills achievement than without using PBFC. The average score obtained in PBFC class is 83.023, higher than the average score of students obtained from class without PBFC which is 76.865. The results of the test of between-subjects effects showed the influence of PBFC on critical thinking skills with the acquisition of Sig .023. This finding is supported by the findings of (Rahmatika et al., 2024) which in his research proved that flipped classroom learning showed a positive effect on improving critical thinking skills, indicating that this pedagogical approach can provide significant benefits to learning outcomes. In addition (Andrini et al., 2019) also proved that the combination of Project-Based Learning and Flipped Classroom had an effect on students' critical thinking skills with significant values. Aspects of critical thinking such as basic clarification, basic support, inference, and advance clarification are the supporting factors (Andrini et al., 2019). PBFC learning model is an excellent learning approach to develop critical thinking skills both theoretically and practically (Listiqowati et al., 2022).

The second analysis result about PBFC on problem solving ability. From the result of data analysis, it shows the influence of PBFC on students' problem solving ability with Sig value .008. The average score of problem solving ability of students who were given learning using PBFC was 79.636. While the students who did the learning activity without PBFC got the average score of 73.313. The average score of problem solving ability is better for students who have done learning activities using PBFC. This finding is in line with research conducted by (Santosa et al., 2023) in his research conducted data analysis with JSAP software. The results showed that the flipped classroom model provided high effectiveness on education students' problem solving skills.

This finding provides information for teachers to apply the flipped classroom model to improve students' problem solving skills in learning. In addition, other findings from the research (Siburian et al., 2022) proved that the Project-based learning model based on Flipped Classroom has a significant effect on problem solving skills. In addition, research conducted by (Aydın & Mutlu, 2023) revealed that students who participated in project-based flipped classroom learning gained higher academic achievement. Project-based flipped classroom learning can not only improve problem-solving skills but also communication skills (Ruslan et al., 2024). Students are actively involved in flipped classroom learning, collaborating on projects, allowing students to apply their knowledge and skills in a practical setting (Smaragdina et al., 2024).

The results of the third analysis of Self-regulated Learning (SRL) on critical thinking skills. The critical thinking ability of students who have high SRL obtained an average score of 84.416. While the critical thinking ability of students with low SRL obtained an average score of 75.472. From these results, it can be seen that students with high SRL are better at acquiring critical thinking skills. The results of the tests of between-sbujects effect obtained a Sig value of .001 so that there is an influence of SRL on students' critical thinking skills. The results of research conducted by (Kusmaryono, 2023) shows that conceptual critical thinking skills, self-learning, and self-regulation have a close and interrelated relationship. Given the importance of self-regulation and self-learning in improving students' critical

thinking skills, it is recommended that teachers develop learning models based on cognitive approaches that suit students' learning styles, such as problem solving, problem posing, or brainstorming solutions (Kusmaryono, 2023).

The results of the fourth analysis of Self-regulated Learning (SRL) on problem solving skills. Based on the results of the test of between-sbujects effects shows the acquisition of Sig .001 so that SRL affects students' problem solving ability. The acquisition of students' problem solving ability is found to be better in students who have higher SRL. Students with low SRL tend to have low problem solving as well. It is found that the average score of problem solving ability in students with high SRL is 80.422. While students with low SRL obtained an average problem solving score of 72.528. (Discussion and citation needed). This finding is in line with research conducted by (Eladl & Polpol, 2020) which in his research revealed that self-regulated learning by students made a significant difference to the improvement of their ability to solve problems. Problem-solving ability contributes significantly to self-regulated learning, both directly and indirectly, and these two variables have a very strong influence (Sari et al., 2024).

The fifth analysis result is related to the influence and interaction of PBFC and SRL on critical thinking ability. Based on the result of data analysis, it is known that the average score of critical thinking ability of students who do PBFC learning with high SRL is 92.045. While students with low SRL only get an average score of 74. Students who follow learning activities using PBFC with high SRL tend to have better critical thinking skills. Based on the result of test of between-subjects effects, it shows that PBFC and SRL affect critical thinking ability with Sig .001. The result of interaction test in Figure 3 shows that there is interaction between PBFC and SRL on critical thinking ability.

In line with research conducted by (Setiyawan et al., 2024) that flipped classrooms significantly improve students' critical thinking skills, particularly highlighting the importance of self-regulated learning. Flipped classroom learning is effective in supporting the development of these skills through an approach that facilitates self-directed learning, resource management and self-reflection (Setiyawan et al., 2024). Where critical thinking requires a supportive teaching and learning environment that can allow students to learn independently before they enter the classroom, online learning can effectively synergize the implementation of flipped classroom with critical thinking skills (Yulian, 2021). Through flipped classroom learning students can summarize, practice, organize and understand the assigned tasks before attending class (Samadi et al., 2024).

The sixth analysis result about the influence and interaction of PBFC and SRL on problem solving ability. Based on the result of test between-subjects of effects, it shows the influence of PBFC and SRL on problem solving ability with Sig value .002. Students who are learning activities using PBFC and have high SRL get a better average score of problem solving ability. Students with low SRL tend to get a lower average score of problem solving ability. Students who follow learning activities using PBFC and have high SRL get an average problem solving score of 87.273. While students who have low SRL get an average problem solving score of 72.273..

Many influential studies have shown and signified the importance of Self-regulated learning strategy types in their overall application by students for optimization and online learning components (Rasheed et al., 2020). There are several important parts of self-regulated learning that provide support

to students including goal setting strategies and skills, deciding on a plan of action and allocating resources (Bui & Johnson, 2024). Flipped classroom learning utilizes students' cognitive self-regulated learning by encouraging students' development as self-directed learners (Samadi et al., 2024). Thus, the flipped classroom can encourage the improvement of students' overall self-regulation by providing an increase in students' motivational regulation (Pamuk & Alagözlü, 2024).

5. Conclusion

This research has produced some important findings about the application of Project Based Flipped Classroom (PBFC) learning and Self-regulated Learning (SLR) as determining variables on critical thinking and problem solving skills. The finding of interaction between PBFC and SRL on critical thinking ability and problem solving ability in this study underlines that project-based learning combined with flipped classroom and Self-regulated Learning factor as the key in the success of achieving better critical thinking ability and problem solving ability. Based on this study, it was found that PBFC has a positive effect on critical thinking and problem solving skills. Students who are taught using PBFC can achieve higher critical thinking ability and problem solving ability than students who are taught without using PBFC.

Self-regulated learning also has a positive influence on the achievement of critical thinking and problem solving skills. Students with low SRL tend to experience difficulties in critical thinking and problem solving. Students with high SRL will be easier in solving learning problems with more critical thinking. Simultaneously, SRL strongly supports learning activities using PBFC. Students who do learning activities using PBFC and have high SRL are much better in achieving critical thinking and problem solving skills. Meanwhile, students who still use PBFC but have low SLR have critical thinking and problem solving skills that are not better than that.

Suggestion

Self-regulated Learning (SRL) is one of the determining factors in PBFC learning on critical thinking and problem solving skills. Considering how important these two abilities are in students to be used later in work. Where problem solving requires critical thinking. So the suggestion from this research needs to be explored more deeply the potential and other possible factors in supporting better achievement. The goal is that the discovery of other factors can contribute to the study as a key to success in boosting critical thinking skills and deeper problem solving.

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