

Enhancing Students' Creative Thinking Skills in Renewable Energy through POPBL-FC with Rasch Model Analysis

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Abstract: Creative thinking skills are essential competencies in 21st-century education, particularly in addressing global challenges related to sustainable energy. However, students' creative thinking skills in physics learning are still relatively low and require improvement through innovative instructional approaches. This study aims to examine the effectiveness of the Project-Oriented Problem-Based Learning-Flipped Classroom (POPBL-FC) model in enhancing students' creative thinking skills in renewable energy topics using Rasch analysis. A quantitative approach was employed, using a quasi-experimental non-equivalent control-group design involving two Grade X classes at a senior high school in Alor Regency, Indonesia. The sample consisted of 33 students in the experimental class and 31 students in the control class, selected through cluster random sampling. The results of the Rasch analysis revealed a significant improvement in students' creative thinking skills in the POPBL-FC group, as indicated by an increase of +2.39 logits, with all students demonstrating positive ability shifts. In contrast, the control group showed relatively lower improvement, with several students exhibiting no significant progress. These findings indicate that the POPBL-FC model is effective in fostering students' creative thinking skills in physics learning, particularly in renewable energy topics. Furthermore, the application of Rasch analysis provides a robust and reliable measurement framework for capturing changes in students' abilities more precisely, thereby contributing to more accurate evaluation in educational research contexts.

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INTRODUCTION

The rapid advancement of science and technology in the 21st century necessitates the improvement of human resources through high-quality education (Chankseliani et al., 2021). Current global challenges are increasingly dominated by complex problems that require higher-order thinking skills, such as creative, analytical, and reflective thinking, as well as collaboration skills (Thornhill-Miller et al., 2023). Therefore, science education, particularly physics, needs to be designed to develop these competencies so that students are better prepared to face real-world challenges (Berg dkk., 2021). Among these competencies, creative thinking skills are considered essential and must be fostered in 21st-century learning (Wati & Sari, 2023; Akpur, 2020). Creative thinking refers to the ability to generate diverse, original, and effective ideas in solving problems (Heard et al., 2025). In the educational context, this skill involves students' ability to understand problems and design solutions using various approaches (Kardoyo et al., 2020). Creative thinking, when combined with critical thinking, contributes to the development of high-quality and sustainable innovations (Putri et al., 2023). Therefore, fostering creative thinking skills is a crucial aspect of physics education.

However, previous studies indicate that students' creative thinking skills in physics learning remain relatively low. Wulandari et al, (2021) found that students' creative thinking skills in global warming topics were categorized as low. Nugroho et al, (2023) also reported that both collaboration and creative thinking skills remained low. Additionally, Nazhifah et al, (2023) revealed that students' creative thinking skills in temperature and heat topics were only at a moderate level, with an average percentage of 54.40%. Another study by Nisa et al, (2024) emphasized that learning models significantly influence students'

creative thinking skills. Preliminary study results further show that students' creative thinking skills are still low, both overall and across key aspects, namely fluency, flexibility, originality, and elaboration (Torrance (1966) in Alabbasi et al, (2022)). Most students fall into the "moderately creative" and "less creative" categories, and none have reached the "highly creative" level. This finding indicates the need for instructional innovation to improve students' creative thinking skills more effectively.

In this study, students' creative thinking skills were assessed based on the Torrance (1966) as cited in Li & Tu, (2024) framework, comprising four indicators: fluency, flexibility, originality, and elaboration. Fluency refers to the ability to generate a large number of ideas, responses, or alternative solutions to a problem within a limited time. Flexibility reflects the ability to approach a problem from different perspectives and produce ideas across various categories. Originality refers to the ability to generate unique, uncommon, and novel ideas that differ from those commonly produced by others. Elaboration represents the ability to expand, refine, and develop ideas in greater detail, making them more comprehensive and applicable (Li & Tu, 2024). These four indicators are widely recognized as core dimensions of creative thinking and were used as the basis for developing the assessment instrument and evaluating students' creative thinking skills in this study.

To enhance creative thinking skills, instructional models that actively engage students in problem-solving and product development are required. Problem-Based Learning (PBL) and Project-Based Learning (PjBL) have been widely recognized as effective in fostering creative thinking due to their emphasis on collaboration, idea exploration, and the development of innovative solutions (Sabila & Diyana, 2025; Hikmah et al., 2023; Riberio, 2023). However, when implemented separately, these models have limitations, thus requiring a more comprehensive integration, namely Project-Oriented Problem-Based Learning (POPBL). POPBL integrates problem-based and project-based learning, enabling students to analyze problems while developing solutions in the form of tangible products (AlAli, 2024; Rahman dkk., 2022; Eliyawati et al., 2020). This model has strong potential to enhance creative thinking through project-based and collaborative activities (Yolanda & Mulyani, 2023; Usman et al., 2024). However, its implementation still faces challenges, such as limited instructional time, insufficient prior knowledge, and low student participation in group work (Pulluri et al., 2024; Rizki & Suprpto, 2024). In addition, the integration of technology is needed to support more effective implementation (AlAli, 2024).

To address these limitations, the Flipped Classroom approach can be integrated with POPBL to form the POPBL-FC model. This approach allows students to acquire foundational knowledge outside the classroom, enabling in-class time to be optimized for discussion, problem-solving, and project development (Bolivar et al., 2023; Li et al., 2022).. Therefore, this integration is expected to enhance the effectiveness of learning in developing students' creative thinking skills (Chua & Islam, 2021).

Furthermore, selecting relevant learning contexts is essential in fostering creative thinking. Renewable energy topics are chosen because they are closely related to global issues and real-world contexts, encouraging students to develop creative solutions grounded in physics concepts. These topics offer strong potential for project-based and contextual problem-solving activities. In addition, the measurement of creative thinking skills in educational research is generally conducted using conventional analysis, which has limitations in capturing students' ability changes in depth. Therefore, this study employs Rasch model analysis to provide a more accurate and comprehensive measurement of students' abilities.

Based on the above rationale, this study aims to investigate the enhancement of students' creative thinking skills in renewable energy topics through the implementation of the Project-Oriented Problem-Based Learning–Flipped Classroom (POPBL-FC) model using Rasch model analysis. Accordingly, this study addresses the following research question: To what extent does the implementation of the POPBL-FC model enhance students' creative thinking skills in renewable energy topics? This study is expected to contribute to the development of innovative instructional models and more robust evaluation methods in physics education.

METHOD

Research Design

This study employed a quantitative approach using a quasi-experimental method with a non-equivalent control group design (Sugiono, 2023). The design involved two groups: an experimental group and a control group, both of which were administered pre-test and post-test measures to assess students' creative thinking skills in renewable energy topics. The experimental group received instruction using the Project-Oriented Problem-Based Learning–Flipped Classroom (POPBL-FC) model, while the control group was taught using the Project-Oriented Problem-Based Learning (POPBL) model. The research design can be expressed as follows:

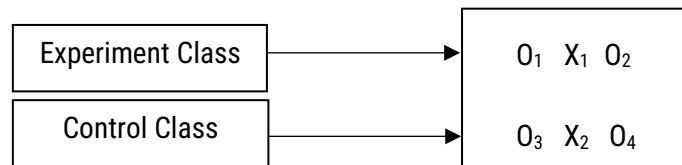


Figure 1. Research flow diagram of the quasi-experimental method with a non-equivalent control group design, adapted from Sugiono, (2023).

Where O_1 and O_3 represent pre-test scores, O_2 and O_4 represent post-test scores, X_1 represents POPBL-FC treatment, and X_2 represents POPBL treatment.

Participants

The study population consisted of all tenth-grade students at a senior high school in Alor Regency, East Nusa Tenggara, Indonesia. The sample was selected using cluster random sampling to ensure representativeness and reduce sampling bias (Sugiono, 2023). The sample comprised two classes: class XC as the experimental group (33 students; 13 males and 20 females) and class XE as the control group (31 students; 15 males and 16 females). Each selected class served as a cluster, and all students in those clusters were included as research participants.

Prior to data collection, the participants were informed about the objectives and procedures of the study by the researcher, and participation was voluntary. Consent to participate was obtained before the research activities were conducted. The study was carried out under an official research permit issued by the Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, with letter number T-10171/UN40.A4.1/PK.03.03/2025, and with permission from the research site.

Instruments

Data were collected using test instruments. The test instruments consisted of an essay-based creative thinking skills test developed based on four indicators, namely fluency, flexibility, originality, and elaboration, adapted from Torrance, (1987) in Chang et al., (2022). All instruments were developed based on relevant theoretical frameworks and were validated before implementation.

The creative thinking skills test instrument was validated by five experts, consisting of three physics education lecturers and two physics teachers. All creative thinking skills test items were assessed based on three aspects: content, construction, and language. The content and construction aspects each comprised five indicators, while the language aspect consisted of four indicators, using a dichotomous rating scheme of "Appropriate" and "Not Appropriate" for each indicator. Furthermore, the validators' assessment results were analyzed to obtain the content validity indices through the calculation of the Content Validity Ratio (CVR) and Content Validity Index (CVI), which consisted of the Item Content Validity Index (I-CVI) and the Scale Content Validity Index/Average (S-CVI/Ave). The instrument was considered valid if the CVR value was greater than or equal to the critical CVR value (Samad et al., 2023; Wilson et al., 2012; Lawshe, 1975). The CVR values obtained from the expert validation of the test instrument were calculated using the following equation (Madadzadeh & Bahariniya, 2023; Samad et al., 2023; Suryadi et al., 2023; lawshe, 1975):

$$CVR = \frac{n_e \frac{N}{2}}{\frac{N}{2}} \quad (1)$$

The standard reference for item validity used the critical CVR value based on a one-tailed test at $\alpha = 0.05$ for five validators, namely 0.736 (Jeldres & Costa, 2023; Wilson et al., 2012). This study employed I-CVI analysis to assess the relevance of each item and S-CVI/Ave to evaluate the overall content validity of the instrument, as these methods are highly recommended for assessing expert agreement regarding content quality. The CVI formula used is as follows: (Jeldres & Costa, 2023; Lawshe, 1975):

$$I - CVI = \frac{\text{Number of validators giving a relevant rating}}{N} \quad (2)$$

The I-CVI criteria consist of three categories. An item with an I-CVI value $\geq 0,79$ is considered valid and accepted without revision. An item with an I-CVI value between 0,70 and $< 0,79$ requires minor revision, while an item with an I-CVI value $< 0,70$ is considered invalid and requires major revision or elimination (Hutting et al., 2025; Rodrigues et al., 2017; Polit & Beck, 2006).

After obtaining the I-CVI results for each item, the overall content validity of the instrument was analyzed using S-CVI/Ave as the average index of expert agreement on item relevance, as this method is considered the most representative and stable for assessing instrument content quality (Hutting et al., 2025; Suryadi et al., 2023; Polit & Beck, 2006). The S-CVI/Ave formula was used to evaluate the overall content validity of the instrument, where an S-CVI/Ave ≥ 0.90 indicates excellent content validity, $0.80 \leq$ S-CVI/Ave < 0.90 indicates acceptable content validity with minor revisions, and S-CVI/Ave < 0.80 indicates low content validity requiring substantial revisions (Hutting et al., 2025; Suryadi et al., 2023; Polit & Beck, 2006):

$$S-CVI/Ave = \frac{\sum I-CVI}{\text{Number of items}} \quad (3)$$

Based on the experts' evaluations, the recapitulation of the content validity analysis results for the fourteen creative thinking skill items in the material aspect is presented in Table 1 below.

Table 1. Results of the Content Validity Analysis of the Critical Thinking Skills Test Instrument for Each Test Item.

Test Item	Validator Assessment Results					CVR	I-CVI	Decision
	V1	V2	V3	V4	V5			
1a	1	0.786	0.929	1	1	0.886	0.943	Valid and accepted
1b	1	0.786	0.929	1	1	0.886	0.943	Valid and accepted
2a	1	1	1	1	1	1	1	Valid and accepted
2b	1	0.786	1	1	1	0.914	0.957	Valid and accepted
3a	1	1	1	1	1	1	1	Valid and accepted
3b	1	1	1	1	1	1	1	Valid and accepted
4a	1	1	0.929	1	1	0.971	0.986	Valid and accepted
4b	1	1	0.929	1	1	0.971	0.986	Valid and accepted
4c	1	1	0.929	1	1	0.971	0.986	Valid and accepted
4d	1	0.929	0.929	1	1	0.943	0.971	Valid and accepted
5a	1	1	1	1	1	1	1	Valid and accepted
5b	1	1	1	1	1	1	1	Valid and accepted
5c	1	1	1	1	1	1	1	Valid and accepted
5d	1	1	1	1	1	1	1	Valid and accepted
						S-CVI/Ave	0.984	Excellent content validity

Based on Table 1, the content validity test results indicate that the CVR values for the 14 items of the creative thinking skills test instrument exceed the minimum threshold. This indicates that the experts agreed that each item was considered relevant and appropriate for use. Furthermore, according to the I-CVI criteria in Table 3.3, the I-CVI results for each test item showed that all items obtained values $\geq 0,79$ and were declared valid without revision, while the S-CVI/Ave value obtained was $\geq 0,90$, indicating that the agreement among validators regarding the overall quality of the instrument was in the excellent category. Therefore, the instrument was declared "content valid and appropriate for use" to measure creative thinking skills, with recommendations for minor revisions.

To analyze reliability, the critical thinking skills instrument was first piloted on 41 eleventh-grade students from a senior high school who had previously studied Renewable Energy material. Reliability testing was then conducted using the Rasch Model approach with the assistance of Winstep software version 3.73. Several criteria used in the reliability test based on this model are as follows:

- a. Person Measurement and Item Measurement Reliability values with an average higher than logit 0,0 indicate that students tend to answer more items correctly, reflecting higher ability levels. The categories for person reliability and item reliability are presented in Table 2 below.

Table 2. Criteria for Person & Item Reliability Values

Person & Item Reliability Values	Category
$r > 0,94$	Excellent
$0,91 \leq r \leq 0,94$	Very Good
$0,81 \leq r < 0,91$	Good
$0,67 \leq r < 0,81$	Fair
$r < 0,67$	Weak

(Sumintono & Widhiarso, 2015)

- b. Cronbach's Alpha values were also used to assess overall reliability, namely the relationship between participant responses and all items in the instrument. The categories of Cronbach's Alpha values according to Sumintono & Widhiarso, (2015) are presented in Table 3 below.

Table 3. Categories of Cronbach's Alpha Values

Cronbach's Alpha Value (α)	Intepretation
$\alpha > 0,80$	Excellent
$0,71 \leq \alpha \leq 0,80$	Good
$0,61 \leq \alpha < 0,71$	Fair
$0,50 \leq \alpha < 0,61$	Poor
$\alpha < 0,50$	Very Poor

Based on the results of the initial trial of the creative thinking skills test instrument on 41 eleventh-grade students, the summary statistical output of person measured reliability, item measured reliability, and Cronbach's Alpha values generated from the Rasch modeling analysis are presented in Figures 2 and Figure 3 below.

SUMMARY OF 41 MEASURED (EXTREME AND NON-EXTREME) Person									
	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	ZSTD	OUTFIT MNSQ	ZSTD	
MEAN	18.7	14.0	-.44	.48					
S.D.	9.2	.0	1.91	.27					
MAX.	35.0	14.0	2.22	1.87					
MIN.	.0	14.0	-6.39	.36	.36	-2.0	.16	-1.9	
REAL RMSE	.57	TRUE SD	1.82	SEPARATION	3.17	Person RELIABILITY	.91		
MODEL RMSE	.55	TRUE SD	1.83	SEPARATION	3.34	Person RELIABILITY	.92		
S.E. OF Person MEAN	= .30								
Person RAW SCORE-TO-MEASURE CORRELATION = .96									
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .92									

Figure 2. Summary Output of Measured Person and Cronbach's Alpha Values from the Rasch Modeling of the Creative Thinking Skills Test Instrument.

SUMMARY OF 14 MEASURED (NON-EXTREME) Item								
	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT		OUTFIT	
					MNSQ	ZSTD	MNSQ	ZSTD
MEAN	54.6	41.0	.00	.24	1.00	.0	.97	-.1
S.D.	15.5	.0	.91	.02	.28	1.3	.32	1.2
MAX.	94.0	41.0	1.36	.28	1.36	1.6	1.45	1.6
MIN.	32.0	41.0	-2.33	.23	.57	-2.4	.55	-2.1
REAL RMSE	.26	TRUE SD	.87	SEPARATION	3.35	Item	RELIABILITY	.92
MODEL RMSE	.24	TRUE SD	.87	SEPARATION	3.59	Item	RELIABILITY	.93
S.E. OF Item MEAN = .25								

Figure 3. Summary Output of Measured Item from the Rasch Modeling of the Creative Thinking Skills Test Instrument.

Based on the categories of Person-Measurement, Item-Measurement Reliability, and Cronbach's Alpha values, referring to the theory of Sumintono & Widhiarso, (2015) in Table 2 and Table 3, the person reliability value = 0,91 and the item reliability value = 0,92 were classified in the "good" category. Meanwhile, the Cronbach's Alpha value = 0,92 was included in the "Excellent" category. These findings indicate that the instrument is stable in distinguishing students' abilities, while the test items have consistent quality and work harmoniously in measuring the same construct. Therefore, the instrument can be declared "reliable" and appropriate for measuring creative thinking skills. The results of the instrument reliability analysis confirm that the developed instrument is consistent, stable, and reliable in measuring creative thinking skills according to the established construct.

Data Collection Procedure

The data collection was conducted in three stages. First, a pre-test was administered to both groups to determine students' initial creative thinking skills in renewable energy topics. The test assessed four indicators of creative thinking based on the Torrance framework: fluency, flexibility, originality, and elaboration. Second, the treatment stage was conducted, during which the experimental group was taught using the POPBL-FC model, while the control group received POPBL instruction across several learning sessions. Third, a post-test using the same indicators was administered to measure improvements in students' creative thinking skills after the intervention.

Data Analysis

The improvement in students' critical and creative thinking skills was analyzed by comparing pre-test and post-test results to identify changes after the learning intervention. As these skills represent latent constructs that cannot be accurately measured using raw scores alone, the analysis employed the stacking technique within the Rasch model using Winsteps version 3.73. This approach enables objective comparison across measurements by converting raw scores into interval-scale logit values, independent of test characteristics. Prior to analysis, the quality of pre-test and post-test data was examined through unidimensionality and item fit testing to ensure that both measurements reflected the same underlying construct (Uzun & Öğretmen, 2021; Boone et al., 2014). Students' abilities were then analyzed by comparing person measures in logit units between pre-test and post-test to identify patterns of improvement, stagnation, or decline. An increase in logit values indicates an improvement in students' abilities (Laliyo et al., 2022; Sunjaya et al., 2021; Bond & Fox, 2015). To support interpretation, a Wright Map (person-item map) was used to visualize the distribution of student abilities and item difficulty on a common logit scale, allowing clearer observation of changes in students' abilities both individually and collectively (Ramadhani et al., 2025; Uzun & Öğretmen, 2021).

RESULT AND DISCUSSION

Result

The POPBL-FC learning model was implemented in the experimental class to train and improve

students' creative thinking skills in renewable energy topics. Data on students' creative thinking skills were obtained through the administration of pre-test and post-test in the experimental class. Furthermore, the improvement in students' creative thinking skills was analyzed using the Rasch model through the stacking technique. The Rasch model analysis of students' creative thinking data in the experimental class was conducted using Winsteps software version 3.73. Through the stacking analysis, logit values of students' abilities were obtained from both the pre-test and the post-test. Changes in these logit values were used to identify shifts in students' creative thinking skills after participating in learning with the POPBL-FC model. The results of the Rasch analysis using Winsteps version 3.73, which illustrate the improvement in students' test results in the experimental class, are presented in Table 4.

Table 4. Logit Value Results of Experimental Class

Number of Student	Measure (logit)			Improvement Criteria
	Pretest	Posttest	Improvement	
1	-4,40	-0,64	+3,76	Positive
2	-3,65	-2,40	+1,25	Positive
3	-3,44	-0,64	+2,80	Positive
4	-1,61	-0,51	+1,10	Positive
5	-2,26	-1,61	+0,65	Positive
6	-3,65	-1,86	+1,79	Positive
7	-2,71	-1,01	+1,70	Positive
8	-3,88	0,18	+4,06	Positive
9	-3,88	-1,99	+1,89	Positive
10	-4,40	-2,12	+2,28	Positive
11	-3,05	-1,99	+1,06	Positive
12	-5,60	-1,86	+3,74	Positive
13	-3,44	0,03	+3,47	Positive
14	-5,10	-1,61	+3,49	Positive
15	-4,72	-2,12	+2,60	Positive
16	-3,44	-1,13	+2,31	Positive
17	-2,12	0,18	+2,30	Positive
18	-2,71	-1,01	+1,70	Positive
19	-4,13	-2,40	+1,73	Positive
20	-3,88	-2,26	+1,62	Positive
21	-2,71	-0,77	+1,94	Positive
22	-5,10	-2,40	+2,70	Positive
23	-4,40	-0,51	+3,89	Positive
24	-3,88	-2,40	+1,48	Positive
25	-3,88	-2,26	+1,62	Positive
26	-3,44	-0,89	+2,55	Positive
27	-5,10	-0,77	+4,33	Positive
28	-2,88	-0,77	+2,11	Positive
29	-2,71	-0,77	+1,94	Positive
30	-5,60	-0,51	+5,09	Positive
31	-3,05	-1,86	+1,19	Positive
32	-4,40	-1,61	+2,79	Positive
33	-2,88	-1,37	+1,51	Positive
Average	-3,70	-1,32	+2,38	Positive

In addition to the comparison of logit values, changes in students' critical thinking skills were also analyzed using the vertical ruler display on the Wright Map. The shift in students' positions on the Wright Map indicates improvement, decline, or no change in students' creative thinking skills after the implementation of POPBL-FC learning in the experimental class. In the interpretation of the Wright Map, green arrows represent an increase in students' abilities after the learning process. The Wright Map

illustrating the distribution and changes in students' critical thinking skills in the experimental class is presented in Figure 4.

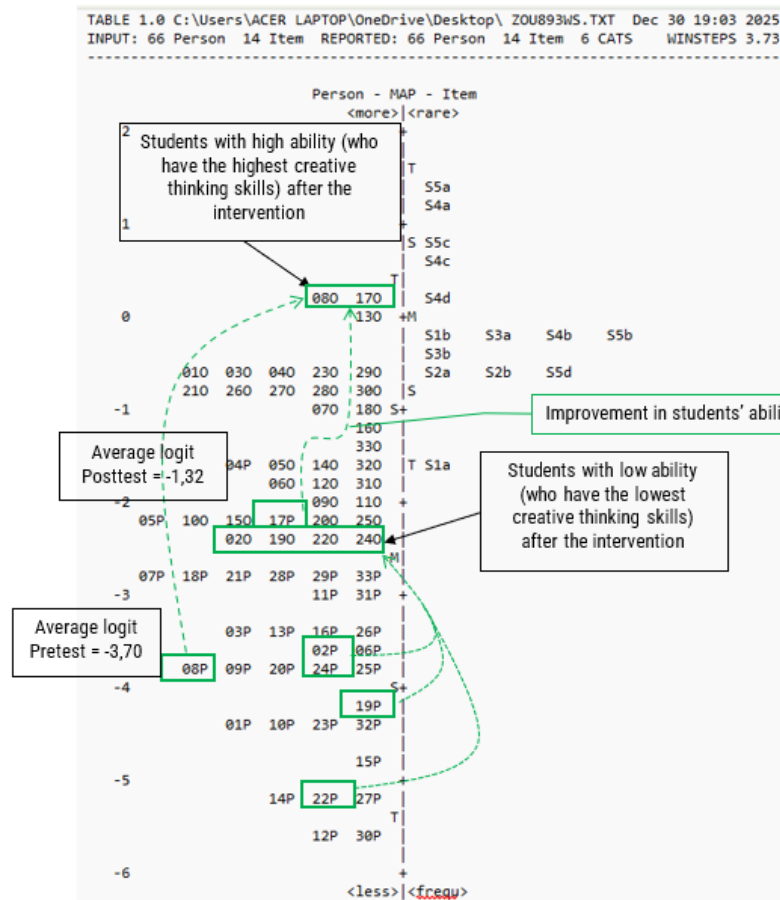


Figure 4. Output Wright Map of Experimental Class

In addition to the experimental class, the improvement in students' creative thinking skills was also analyzed in the control class, which received instruction using the POPBL model, in order to compare the level of improvement between the two groups. Data on students' creative thinking skills in the control class were collected through pre-test and post-test using the same instruments as those administered in the experimental class. The improvement in students' creative thinking skills in the control class was also analyzed using the Rasch model with the stacking technique. The results of the logit value analysis of the creative thinking skills test in the control class, before and after the implementation of the learning model are presented in Table 5.

Table 5. Logit Value Results of Control Class

Number of Student	Measure (logit)			Improvement Criteria
	Pretest	Posttest	Improvement	
1	-2,19	-1,31	+0,88	Positive
2	-2,45	-0,52	+1,93	Positive
3	-3,08	-0,27	+2,81	Positive
4	-2,75	0,94	+3,69	Positive
5	-3,08	-2,45	+0,63	Positive
6	-2,75	0,81	+3,56	Positive
7	-1,94	-0,81	+1,13	Positive
8	-2,45	-2,45	+0,00	No Change
9	-3,08	-0,96	+2,12	Positive
10	-2,19	-1,51	+0,68	Positive

Number of Student	Measure (logit)			Improvement Criteria
	Pretest	Posttest	Improvement	
11	-2,19	-0,02	+2,17	Positive
12	-1,94	-0,39	+1,55	Positive
13	-2,45	-0,14	+2,31	Positive
14	-2,75	-0,66	+2,09	Positive
15	-2,75	0,69	+3,44	Positive
16	-2,75	-0,27	+2,48	Positive
17	-1,94	1,08	+3,02	Positive
18	-3,98	0,94	+4,92	Positive
19	-2,75	-0,14	+2,61	Positive
20	-2,45	-1,72	+0,73	Positive
21	-3,98	-2,19	+1,79	Positive
22	-2,19	-0,66	+1,53	Positive
23	-1,94	-0,66	+1,28	Positive
24	-3,47	-2,45	+1,02	Positive
25	-1,72	-0,81	+0,91	Positive
26	-2,75	0,21	+2,96	Positive
27	-6,04	-3,98	+2,06	Positive
28	-4,77	-2,19	+2,58	Positive
29	-2,45	-2,45	+0,00	No Change
30	-2,19	-1,51	+0,68	Positive
31	-2,75	-2,19	+0,56	Positive
Average	-2,67	-0,80	+1,87	Positive

In the control class, one student (Student 27) obtained a pre-test score of zero, resulting in an extreme logit estimate (minimum measure). This data point was retained in the Rasch modeling analysis. Furthermore, changes in students' creative thinking skills in the control class were analyzed using the vertical ruler display on the Wright Map, where pre-test positions were indicated by the code "P" and post-test positions by the code "O". Shifts in students' positions on the Wright Map indicate improvement, decline, or no change in creative thinking skills following the implementation of the POPBL model.

In the interpretation of the Wright Map, green arrows indicate an increase in students' abilities after the learning process, while yellow arrows indicate no improvement. The Wright Map illustrating the distribution and changes in students' creative thinking skills in the control class is presented in Figure 5.

DISCUSSION

Based on the Rasch model analysis, the improvement in creative thinking skills in the class implementing the POPBL-FC model was greater than that in the class implementing the POPBL model. The average logit score in the POPBL-FC class increased from -3.70 in the pre-test to -1.32 in the post-test, with an average gain of +2.38 logits, indicating a consistent positive shift in students' abilities. The Wright Map analysis also revealed that all students in the POPBL-FC class experienced improvement, with no cases of decline or stagnation. This suggests that the POPBL-FC model is effective across different levels of student ability, from low to high achievers. In contrast, although the POPBL class also showed improvement (average gain of +1.87 logits), the increase was less substantial and more varied, with some students showing minimal or no improvement. The Wright Map further illustrates that the distribution of student abilities in the POPBL-FC class shifted more consistently toward higher logit levels after the intervention, with a greater proportion of students moving closer to or above the mean item difficulty. This indicates better alignment between students' abilities and the level of cognitive demand of the test items. Meanwhile, in the POPBL class, although a positive shift was also observed, the post-test distribution remained more dispersed, and several students remained below the item difficulty threshold, suggesting less uniform development of creative thinking skills. Overall, these findings suggest that the POPBL-FC model not only enhances average performance but also promotes more consistent improvement across

different ability levels, as reflected in the more compact, upward-shifted distribution of person measures in the Wright Map compared to the POPBL class.

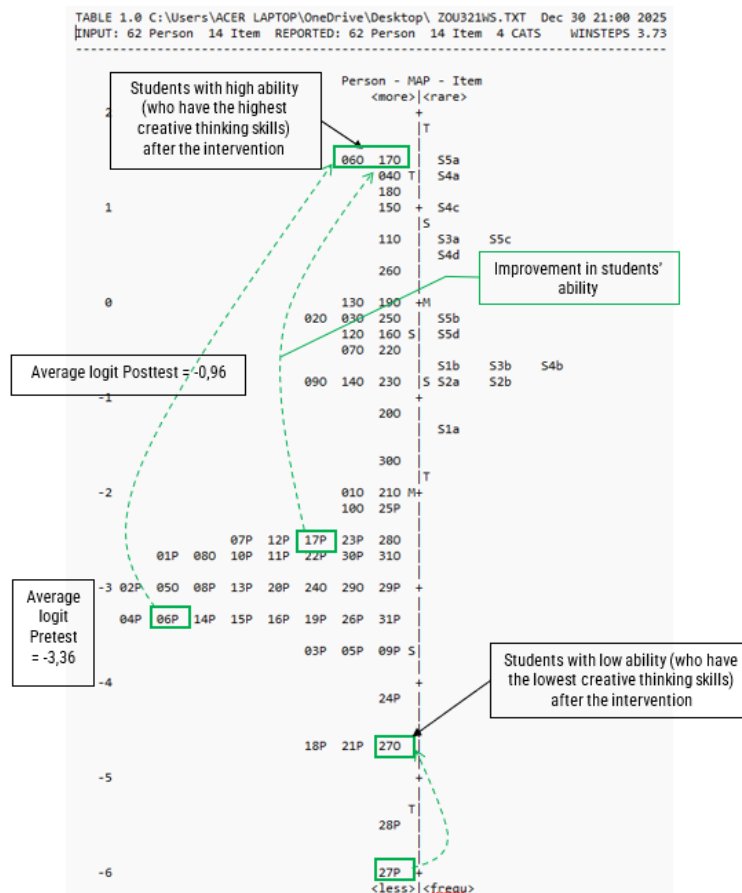


Figure 5. Wright Map Output of Control Class

These findings are consistent with previous studies highlighting the effectiveness of Project-Oriented Problem-Based Learning (POPBL) in enhancing creative thinking. Research by Chang et al., (2022) demonstrated that interdisciplinary POPBL significantly improves students' creativity through engagement in authentic problem-solving and interdisciplinary project activities. Similarly, Eliyawati et al., (2019) reported that POPBL integrated with STEM promotes creativity by encouraging students to develop innovative solutions through project-based learning. These results support the present study, where POPBL-based instruction contributed to the development of students' creative thinking skills.

However, the integration of the flipped classroom within POPBL, as implemented in the POPBL-FC model, provides additional benefits. The flipped classroom allows students to access learning materials before class, enabling them to build initial conceptual understanding independently. As a result, in-class learning can focus on higher-order thinking activities such as discussion, collaboration, problem-solving, and idea development. This structure enhances students' opportunities to actively construct knowledge and explore multiple perspectives. This finding aligns with Harjono et al., (2022), who found that the flipped classroom supported by video improves students' creative thinking through increased engagement and independent learning. Furthermore, Chua & Islam, (2021) showed that the hybrid Project-Based Learning–Flipped Classroom model enhances student engagement and learning outcomes by emphasizing active participation and idea exploration.

From a cognitive perspective, the effectiveness of flipped classroom can be explained by its role in reducing cognitive load and optimizing classroom time for higher-order thinking processes. Van Alten et al., (2019) found that flipped classroom improves learning outcomes and student satisfaction by enabling deeper learning during face-to-face sessions. In this study, such conditions allowed students to focus more on creative processes, including generating, elaborating, and refining ideas.

In addition, recent studies further support the role of flipped classroom in enhancing higher-order thinking skills. Research has shown that flipped classroom-based learning improves students' problem-solving abilities and learning independence, which are closely related to creative thinking. Likewise, Nuriyah et al., (2021) found that flipped STEM classroom significantly improves students' creativity and conceptual understanding in physics learning. Furthermore, the improvement in the POPBL-FC class was consistently observed across all subtopics of renewable energy, each showing moderate improvement. In contrast, the POPBL class demonstrated low improvement across all subtopics. This indicates that the integration of flipped classroom strengthens the effectiveness of POPBL in facilitating creative thinking, particularly in physics learning contexts. Despite these positive findings, variations in students' improvement were still observed, indicating differences in students' readiness and adaptability to problem-based and project-based learning environments. Additionally, the limited duration of the intervention (single cycle) may have constrained the optimal development of creative thinking skills. Creative thinking requires iterative processes involving exploration, revision, and refinement of ideas, which cannot be fully achieved within a short instructional period.

From a pedagogical perspective, the effectiveness of the POPBL-FC model can be attributed to its emphasis on authentic problem-solving and project-based learning in real-world contexts. In renewable energy learning, students are encouraged not only to understand theoretical concepts but also to design innovative ideas and solutions related to energy utilization. This approach fosters creativity by engaging students in meaningful and contextual learning experiences. Overall, the findings confirm that the POPBL-FC model is both statistically and pedagogically effective in enhancing students' creative thinking skills. The integration of project-based learning, problem-solving, and flipped classroom creates a comprehensive learning environment that supports the development of creativity and other essential 21st-century skills.

Implications

The findings of this study have important implications for physics education, the development of creative thinking, and future instructional practices. First, the results demonstrate that the POPBL-FC model can serve as an effective pedagogical approach for physics learning, particularly in topics that require students to apply scientific concepts to authentic real-world problems, such as renewable energy. By integrating project-oriented problem solving with flipped learning, the model promotes meaningful learning experiences that connect theoretical knowledge with practical applications. Second, the study contributes to the development of students' creative thinking skills by providing a learning environment that encourages idea generation, flexibility in problem-solving, originality, and elaboration. The consistent improvement observed across students with different initial ability levels suggests that POPBL-FC can support the development of creative thinking in a more inclusive manner. These findings highlight the importance of combining pre-class independent learning with collaborative in-class activities to foster higher-order thinking skills. Third, the findings offer practical implications for future instructional practices. Physics teachers are encouraged to adopt the POPBL-FC model as an alternative instructional strategy that optimizes classroom time for discussion, project development, and creative problem-solving while allowing students to acquire foundational knowledge before class. Curriculum developers may also consider incorporating learning designs that integrate flipped classroom principles with project- and problem-based learning approaches to better align physics instruction with 21st-century educational goals. However, the variation in students' improvement indicates the need to consider learners' readiness, motivation, and engagement when implementing POPBL-FC. Future studies should investigate these factors and examine the long-term impact of the model across different physics topics and educational contexts.

Research Limitation

This study has several limitations that should be considered when interpreting the findings. First, variations in the improvement of students' creative thinking skills were observed in both classes, indicating differences in students' readiness and ability to adapt to problem- and project-based learning approaches. These differences may have influenced the effectiveness of the learning intervention and contributed to inconsistent learning outcomes among students. Second, the intervention was

implemented in only a single learning cycle. Since creative thinking skills develop through an iterative process that involves generating, revising, and refining ideas, the limited duration of the intervention may have restricted students' opportunities to develop their creative potential fully. Furthermore, the instructional material used in this study was limited to a PDF-based e-module, which offered a relatively low level of interactivity and was not specifically designed to accommodate the characteristics of the POPBL-FC model for fostering creative thinking skills. In addition, students' readiness for independent learning using e-modules was relatively low, as some students experienced difficulties in accessing, understanding, and utilizing the learning materials effectively before classroom activities.

Recommendations

Future research is recommended to implement the POPBL-FC learning intervention across multiple learning cycles to provide students with more extensive opportunities to engage in idea exploration, revision, and creative solution development, thereby supporting the gradual development of creative thinking skills. Further studies should also focus on developing and evaluating a POPBL-FC-based e-module specifically designed to enhance creative thinking skills. Such an e-module could be developed as an interactive digital learning resource that integrates pre-class learning materials, instructional videos, simulations, authentic problem scenarios, and contextual project-based activities. Moreover, the learning activities embedded within the e-module should be intentionally designed to facilitate the development of the key dimensions of creative thinking skills, namely fluency, flexibility, originality, and elaboration. Future studies are also encouraged to investigate strategies for improving students' readiness for self-directed learning, including the provision of training or orientation sessions on the effective use of e-modules prior to implementation.

CONCLUSION

This study provides empirical evidence that the integration of Project-Oriented Problem-Based Learning with a Flipped Classroom approach (POPBL-FC) is more effective in fostering students' creative thinking skills than conventional POPBL. Students in the POPBL-FC class showed greater improvement in creative thinking skills in renewable energy topics, as indicated by higher logit scores and more consistent improvement across ability levels. This indicates that POPBL-FC is more effective in enhancing creative thinking skills compared to POPBL. Beyond learning outcomes, the findings support the use of hybrid pedagogical models that integrate problem-based learning, project-oriented activities, and flipped learning to develop higher-order thinking skills. The synergy between pre-class preparation and in-class collaborative activities helps develop key aspects of creative thinking, including fluency, flexibility, originality, and elaboration. From a pedagogical perspective, integrating flipped classroom into POPBL improves instructional efficiency and student engagement, enabling active knowledge construction and creative problem-solving in renewable energy learning. Thus, POPBL-FC is a relevant strategy for supporting 21st-century skills, particularly creativity. However, this study is limited by students' unfamiliarity with the model, variations in learning readiness, and the use of a single instructional cycle. Future research should apply the model across multiple cycles and contexts to further examine its effectiveness and sustainability.

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