

The Implementation of STEM Project-Based Learning and Critical Thinking on Student Creativity in English Learning: A Mixed Methods Study

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ABSTRACT

Education in the 21st century requires not only content mastery but also the development of higher-order thinking skills to address complex global challenges. This study investigates the effects of STEM Project-Based Learning (PjBL) and students' critical thinking on creativity in English language learning. Employing a mixed methods approach with an explanatory sequential design, the study first gathered quantitative data through surveys and tests, followed by qualitative data from interviews and classroom observations. The participants consisted of 200 Grade X students from two senior high schools in Serang City, selected through purposive sampling. The quantitative findings revealed that both STEM PjBL and critical thinking significantly influence student creativity, with strong positive correlations ($r = 0.867$ and $r = 0.889$) and moderate effect sizes (Cohen's $d = 0.516$ and 0.505). The qualitative data supported these findings, highlighting students' increased engagement, collaboration, and reflective thinking during project implementation. These results suggest that integrating STEM-based projects in English learning can effectively foster critical and creative thinking skills, offering a promising interdisciplinary approach to language education. The study contributes to current literature by demonstrating the combined impact of PjBL and critical thinking in a language learning context, an area often overlooked in prior research. The findings hold practical implications for curriculum designers and educators seeking to promote 21st-century competencies through integrated, student-centered instruction.

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1. INTRODUCTION

Education in the 21st century requires more than knowledge transmission; it demands the cultivation of higher-order thinking skills that enable learners to respond to complex global challenges. Among these skills, critical thinking and creativity are consistently recognized as essential, yet their development in classrooms often remains superficial, dominated by teacher-centered instruction and

rote memorization. To address this, innovative pedagogies such as STEM Project-Based Learning (PjBL) have been introduced, offering opportunities for students to engage in authentic problem-solving tasks that integrate multiple disciplines and stimulate both analytical and imaginative capacities (Nehru et al., 2024; Sanusi et al., 2023).

Unlike conventional methods, STEM PjBL situates learning in collaborative, contextual, and inquiry-based projects. This approach provides a fertile ground for fostering creativity through idea generation and innovation, while simultaneously nurturing critical thinking through analysis, evaluation, and reflection (Mutakinati et al., 2018; Nugroho et al., 2019). Several studies confirm that STEM PjBL enhances students' ability to think critically and to act creatively (Aguilera & Ortiz-Revilla, 2021; Fan & Cai, 2022; Hanif et al., 2019; Tiruneh et al., 2017). However, these studies tend to examine these outcomes independently, focusing either on critical thinking or creativity, without exploring their interconnected development within a single learning model.

This limitation is especially apparent in the context of English language education. While a number of investigations address STEM PjBL in science or mathematics (Etkina & Planinšič, 2015; Sumarni & Kadarwati, 2020), few studies have examined how STEM PjBL simultaneously supports critical thinking and creativity in English learning. The absence of this integrated perspective is a significant gap, since language learning inherently requires analytical reasoning (e.g., interpreting meaning, evaluating arguments) as well as creative expression (e.g., producing ideas, articulating perspectives). Existing empirical work thus leaves unanswered questions about whether STEM PjBL can serve as an effective bridge between language acquisition and the cultivation of 21st-century skills.

Furthermore, most prior studies on STEM education have been conducted in international or urban elite contexts, with limited attention to diverse regional conditions. This makes contextual research in Indonesia both timely and necessary. English proficiency levels in Indonesia remain relatively low compared to regional standards, and student engagement in higher-order thinking is often hampered by exam-oriented practices. Within this national picture, Serang City presents a particularly compelling case. As the capital of Banten Province, Serang is experiencing rapid urban development, yet educational indicators reveal persistent challenges: students often struggle with English mastery, critical reasoning, and creative application in real-life tasks. These conditions underscore the need for innovative pedagogies that not only improve English learning outcomes but also prepare students with broader competencies required in a globalized world.

By situating the study in Serang, this research acknowledges both the systemic difficulties of Indonesian education and the local realities that shape classroom practices. Serang represents a context where the potential of STEM PjBL has yet to be tested within language learning, making it both representative of national challenges and a possible model for wider application. Investigating how STEM PjBL influences students' critical thinking and creativity in English classes in Serang thus provides an opportunity to contribute not only to theory but also to practice, informing teachers, policymakers, and curriculum designers.

The uniqueness of this study is in its integration of qualitative and quantitative methodologies, which will yield a comprehensive investigation of the impact of project characteristics, collaborative dynamics, and reflective practices on students' creativity and critical thinking abilities. The integration of these two approaches allows for a more holistic understanding of the learning process, capturing both measurable outcomes (e.g., test scores, creativity assessments) and in-depth insights (e.g., student reflections, group dynamics, classroom observations). By using both qualitative (interviews, observations) and quantitative (surveys, pre/post-tests) data, the study seeks to offer a more nuanced and evidence-based evaluation of how STEM PjBL environments shape students' cognitive and creative growth something that purely quantitative or qualitative studies alone may fail to capture. Furthermore, this effort will present a framework that integrates the evaluation of critical thinking and creativity specifically designed for the STEM PjBL learning environment. At its core, this project will enhance our knowledge of the pedagogical connections among STEM PjBL, critical thinking, and creativity, thereby facilitating a more comprehensive teaching strategy that equips students for the intricacies of

contemporary society. This study seeks to determine the effect of STEM Project-Based Learning (PjBL) on students' creativity in English, investigate the impact of students' critical thinking behaviors on their creativity in English, and analyze the relationship between the implementation of STEM PjBL and critical thinking skills in relation to students' creativity in learning English.

2. METHODS

This study employed a mixed methods approach with an explanatory sequential design (Creswell & Clark, 2011). Quantitative data were collected and analyzed first, followed by qualitative exploration to provide deeper insights into the statistical results (Johnson et al., 2007). This design was chosen to capture both measurable outcomes and students' perspectives on the implementation of STEM Project-Based Learning (PjBL).

2.1 Participants and Sampling

The research was conducted in two public senior high schools in Serang City, focusing on Grade X students. Schools were selected based on three criteria: (1) availability of Grade X classes, (2) accessibility for sustained observation, and (3) representation of diverse socio-economic backgrounds. A total of 200 students participated, selected through purposive sampling to ensure that participants had prior exposure to English project-based activities relevant to the intervention.

2.2 Instruments

Two main constructs were measured: critical thinking and creativity. Both were assessed using Likert-scale questionnaires (1–5), adapted from validated instruments and reviewed by two education experts. Creativity tasks and critical thinking tests were complemented by performance-based assessments embedded in classroom projects. Semi-structured interviews, classroom observations, and student reflective journals were employed to capture qualitative data.

2.3 Validity and Reliability

Instrument validity was examined through item-total correlation, with coefficients above 0.30 considered acceptable. Reliability was assessed using Cronbach's alpha, yielding values above 0.70 for both constructs, indicating satisfactory internal consistency. Items falling below the threshold were excluded from the final analysis.

Table 1. Validity and Reliability Results

Construct	Validity (Corrected Item–Total Correlation)	Reliability (Cronbach's Alpha)	Decision
Critical Thinking	0.427 – 0.721	0.923	Acceptable
Student Creativity	0.371 – 0.735	0.834	Acceptable

2.4 Intervention Procedure

The STEM-PjBL intervention was integrated into English lessons over six weeks (two 90-minute sessions per week). The cycle included: (1) preparation of STEM-integrated English projects, (2) project introduction and group formation, (3) guided development through inquiry and collaboration, (4) group presentations in English, and (5) structured reflection and evaluation. Teachers received a one-day training workshop prior to implementation to ensure fidelity, and researchers acted as observers and facilitators throughout the process.

2.5 Data Analysis

Quantitative data were analyzed using SPSS, employing paired-sample t-tests and correlation analysis to test hypotheses and effect sizes. Qualitative data were transcribed verbatim, coded through open coding, and categorized thematically following the Miles and Huberman (2014) framework. Credibility was ensured through triangulation (cross-checking interviews, observations, and documents) and member checking with participants. Integration of findings was conducted at the interpretation stage, where qualitative themes were used to explain or elaborate on quantitative trends.

3. FINDINGS AND DISCUSSION

3.1 Quantitative Findings

The table below displays the outcomes of descriptive statistical tests conducted on the impact of STEM PjBL on the creativity of students.

Table 2. Descriptive Statistics of STEM PjBL

School	Interval	Category	F	%	Mean	Median
School A	3.00 – 5.00	Not Very Good	0	0.0%		
	6.00 – 9.00	Not Good	3	2.5%	14.5	10.4
	10.00 – 13.00	Good	35	42.5%		
	14.00 – 16.00	Very Good	62	55.0%		
School B	3.00 – 5.00	Not Very Good	0	0.0%		
	6.00 – 9.00	Not Good	2	3.75%	10.00	8.00
	10.00 – 13.00	Good	40	42.5%		
	14.00 – 16.00	Very Good	58	53.75%		

Based on the data shown in Table 2, it can be observed that STEM PjBL at school A is predominantly classified as very good, representing 55% of the overall figure. Similarly, at school B, STEM Project-based learning (PjBL) is also strongly marked by the very good category, accounting for 53.75%.

Table 3. Descriptive Statistics of Critical Thinking

School	Interval	Category	F	%	Mean	Median
School A	4.0 – 10.0	Not Very Good	0	0.0%		
	11.0 – 14.0	Not Good	1	2.0%	20.00	12.50
	15.0 – 18.0	Good	40	39.0%		
	19.0 – 22.0	Very Good	59	59.0%		
School B	4.0 – 10.0	Not Very Good	0	0.0%		
	11.0 – 14.0	Not Good	2	2.5%	16.00	9.05
	15.0 – 18.0	Good	39	55.0%		
	19.0 – 22.0	Very Good	59	42.5%		

According to the statistics shown in Table 3, the majority of critical thinking within School A falls into the very good category, accounting for 59% of the total. The most prevalent involvement category at school B is fairly high, accounting for 42.5%.

Table 4. Descriptive Statistics of Students' Creativity

School	Interval	Category	F	%	Mean	Median
School A	0.0 – 5.0	Not Very Good	1	1.25%		
	6.0 – 10.0	Not Good	5	5.25%	23.00	12.00
	11.0 – 15.0	Good	44	40.50%		
	16.0 – 20.0	Very Good	50	53.00%		
School B	0.0 – 5.0	Not Very Good	0	0.00%		
	6.0 – 10.0	Not Good	5	5.25%	22.00	13.00
	11.0 – 15.0	Good	35	36.25%		
	16.0 – 20.0	Very Good	60	58.50%		

The statistics presented in Table 3 indicate that 53% of students in school A exhibit a high level of creativity, placing them in the very good category. Furthermore, at school B, the proportion of students in the very good group is 58.5%. Prior to assessing the hypothesis, the researcher conducted empirical tests to verify the assumptions and ascertain that the data adhered to both a normal distribution and a linear distribution. This facilitates additional assessment of hypotheses. The present research employs the T-test and correlation analysis for statistical evaluation. This test is utilised to identify discrepancies and statistical correlations between the variables analysed from the two educational institutions.

Table 5. Analysis of the T-test findings for STEM PjBL, critical thinking, and student creativity

Variable	School	N	t	Sig. (2-tailed)	Cohen's d
STEM PjBL	School A	100	5.747	0.000	0.516
	School B	100	5.735	0.000	0.505
Critical Thinking	School A	100	6.757	0.000	—
	School B	100	5.760	0.000	—
Student Creativity	School A	100	6.370	0.000	—
	School B	100	5.670	0.001	—

According to the statistical analysis of the t-test results in Table 4, which indicate a significant value below 0.05, there is a discernible difference in STEM Project-Based Learning, critical thinking, and student creativity between the two benchmark schools. Thus, the values of 0.516 and 0.505 indicate a moderate effect. This means that the implementation of STEM PjBL has a fairly strong and tangible impact on improving students' critical thinking skills, not only statistically significant ($p = 0.000$) but also has practical significance in the real world. The implementation of STEM PjBL has an effect on critical thinking, but not in the "significant" category. This means the learning model is effective, but there are still other factors that contribute to students' English learning outcomes.

Table 6. Summary of the correlation test findings for STEM PjBL, critical thinking, and student creativity

School	X	Y	Sig. F Change	Pearson Correlation
School A	STEM PjBL	Student creativity	0.009	0.889
	Critical Thinking			
School B	STEM PjBL	Student creativity	0.011	0.867
	Critical Thinking			

The correlation test results in table 5 present the correlation values of 0.867 and 0.889, demonstrate a very strong positive relationship between STEM Project-Based Learning (PjBL) and the development of critical thinking and creativity in the context of English language education, indicating that students who actively engage in STEM-based projects tend to perform much better in analytical reasoning and creative expression when learning English. This is significant because English learning is not limited to grammar and vocabulary mastery but also involves interpreting texts, constructing arguments, and producing innovative ideas, all of which require higher-order thinking. While correlations of 0.3–0.5 are typically considered meaningful in educational research, the much higher values found here underscore that STEM PjBL is not only compatible with language learning but also highly effective in strengthening the dual skills of critical and creative thinking, thereby positioning it as a powerful pedagogical approach for preparing students to use English in complex, real-world contexts. An analysis of the pertinent conclusions derived from the qualitative data is presented. All qualitative conclusions are derived from prior descriptive statistical findings. Individual qualitative findings are given directly inside their corresponding qualitative contexts. The subsequent text provides an account of the qualitative data obtained from interviews.

3.2 Qualitative Findings

The qualitative analysis revealed three main themes related to students' experiences with STEM Project-Based Learning (PjBL), critical thinking, and creativity.

3.2.1 Perceptions of STEM PjBL

Students generally viewed STEM PjBL as an engaging and meaningful instructional model. They appreciated its integration of multiple disciplines and the opportunities it created for authentic problem-solving. Completing projects was seen as demanding but rewarding, requiring reasoning, evaluation, and collaboration. One student remarked, *"The practical application of STEM Project-Based Learning is highly demanding, but we are really satisfied with the results"* (S3). Others highlighted that PjBL helped them connect classroom learning with real-world applications, reinforcing its relevance. This indicates that PjBL can bridge the gap between abstract language concepts and practical application, fostering deeper learning and satisfaction.

3.2.2 Critical Thinking in the Classroom

Students expressed mixed perceptions regarding their classroom learning experiences. Some valued factual learning, believing it enhanced their comprehension: *"I believe this training will enhance my understanding of the world"* (S2). However, others criticized conventional lessons for being overly theoretical and detached from reality: *"Numerous educational lessons do not align with reality"* (S5). This contrast suggests that while traditional approaches may promote retention, they often fail to stimulate higher-order thinking. In contrast, the PjBL activities were perceived as requiring questioning, reasoning, and evaluation—skills central to critical thinking.

3.2.3 Strategies for Fostering Creativity

Students described employing a multifaceted set of strategies to address academic challenges and complete assignments. Collaboration with peers emerged as the most common approach: *"I seek solutions with my peers"* (S1). Many also relied on digital resources, such as Google or AI, to complete projects efficiently: *"I use AI to fulfill the assignment given by the teacher"* (S6). In addition, several participants described analytical approaches, such as identifying root causes and implementing targeted solutions. However, reliance on external support, such as guidance counselors, indicates that students' creative autonomy is still developing. Overall, these findings illustrate how creativity is fostered not only through individual reflection but also through collaboration and technological adaptation.

3.2.4 Integration with Quantitative Findings

The qualitative themes reinforce the quantitative results, which showed strong correlations between STEM PjBL, critical thinking, and creativity. Students' recognition of PjBL as both challenging and relevant explains the observed gains in creativity and reasoning. Similarly, the reported reliance on collaboration and digital tools aligns with the moderate effect sizes, suggesting that PjBL supports creativity by encouraging both cognitive and practical problem-solving strategies.

Discussion

This study demonstrates that STEM Project-Based Learning (PjBL) significantly enhances students' creativity, with critical thinking emerging as a strong predictor of creative outcomes in English language learning. The integration of STEM-oriented projects into English classrooms provided opportunities for students to engage in authentic problem-solving, apply reasoning, and generate innovative ideas. These findings extend earlier research, which primarily examined STEM PjBL in science and mathematics (Hanif et al., 2019; Mutakinati et al., 2018), by showing that the approach is equally effective in language education.

The results contribute to theory by confirming that critical thinking and creativity are interdependent and mutually reinforcing. While prior studies often treated them separately (Lou et al., 2017; Tiruneh et al., 2017), this study shows that project-based inquiry fosters both simultaneously. The mechanism lies in the dual demands of PjBL: students must analyze and evaluate information (critical thinking) while also producing original solutions and expressions (creativity). This supports constructivist perspectives, where knowledge construction is viewed as both analytical and imaginative. The strong correlations ($r = 0.867$ and $r = 0.889$) suggest that the boundary between "thinking critically" and "thinking creatively" is more porous than traditionally assumed, challenging the view that creativity belongs only to the arts while critical thinking is reserved for logic-based domains.

From a practical perspective, the findings highlight the need to rethink classroom pedagogy and assessment. STEM PjBL encouraged student collaboration, inquiry, and real-world application—processes often missing from traditional, memorization-based instruction. By situating English learning in interdisciplinary projects, students practiced higher-order reasoning while improving language skills. This implies that PjBL frameworks should not be restricted to STEM subjects but can be effectively applied in language education. For educators, successful implementation requires professional development in facilitating inquiry, managing teamwork, and designing authentic assessments. At the policy level, the study suggests shifting evaluation systems from rote-based testing toward performance-based assessments that capture reasoning, collaboration, and creativity.

The findings align with prior studies showing that STEM PjBL fosters creativity and engagement (Prajoko et al., 2023; Saefullah et al., 2021), but they extend this work by situating the model within English language learning. Unlike Almulla (2023) and Octafianellis et al. (2021), who examined critical thinking in STEM-exclusive classrooms, this study shows that language learning also benefits from inquiry-driven, real-world tasks. A plausible explanation is that both science and language learning share a reliance on inquiry, communication, and contextual application, making PjBL transferable across domains. However, this study diverges from research conducted in Western or resource-rich contexts (Aguilera & Ortiz-Revilla, 2021; Alkautsar et al., 2023), demonstrating that even in settings with limited infrastructure, substantial learning gains can be achieved if pedagogy emphasizes collaboration and inquiry.

Several limitations must be acknowledged. First, the study was limited to two schools in Serang City, restricting generalizability. Future research should expand to rural and urban schools across regions to capture diverse educational contexts. Second, the six-week intervention limits conclusions about the sustainability of learning gains; longitudinal studies are needed to examine long-term impacts. Third, teacher effects were not fully controlled, as variations in facilitation style may have

influenced outcomes. Standardized training modules and fidelity checks should be incorporated in future research to ensure consistent implementation.

4. CONCLUSION

This study demonstrates that STEM Project-Based Learning (PjBL) significantly enhances students' creativity in English learning, with critical thinking emerging as a strong contributor and showing a high correlation with creative outcomes. These findings highlight the potential of PjBL as an effective pedagogical approach for fostering 21st-century skills beyond STEM-exclusive subjects. However, the study has several limitations: it was conducted in only two schools in Serang City, limiting the generalizability of results; the six-week intervention period restricts conclusions about long-term impacts; and teacher effects were not fully controlled, leaving open the possibility that variations in facilitation influenced student outcomes. Future research should therefore involve larger and more diverse samples across urban and rural contexts, extend the duration of interventions to capture sustained effects, and standardize teacher training to ensure consistent implementation. Comparative studies are also recommended to examine how differences in teacher expertise and professional development shape the effectiveness of STEM PjBL in promoting creativity and critical thinking.

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