



Implementation of Project-Based e-LKPD on Banana Peel Waste Processing to Enhance Students' Creative Thinking Skills

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ABSTRACT

The lack of creative thinking skills of students in learning alternative electrical energy highlights the need for more contextual and project-oriented learning activities. This study investigated the effectiveness of project-based electronic worksheets on banana peel waste processing implemented through the PjBL-STEM learning model in improving students' creative thinking skills. A quasi-experimental design supported by qualitative interview data was employed in this research to obtain a deeper understanding of students' learning experiences. The participants consisted of two classes from a state senior high school in Lampung, Sumatra. Data were collected using essay-based test instruments developed to assess the indicators of fluency, flexibility, originality, and elaboration. The quantitative findings showed that students' creative thinking skills improved significantly after the implementation of the project-based e-LKPD, as indicated by high N-gain scores of 0.72 and 0.75, along with significant paired sample t-test results (sig. < 0.05). Furthermore, no statistically significant difference was found based on gender (sig. > 0.05), although several indicators demonstrated descriptive variations. Overall, the implementation of project-based e-LKPD through the PjBL-STEM learning model contributed positively to the development of students' creative thinking skills and may serve as an innovative alternative in physics learning.

Keywords: creative thinking skills, e-LKPD, gender, PjBL-STEM

INTRODUCTION

Global developments in technology, information, and society have encouraged educational systems to prepare learners with competencies relevant to modern challenges (Gonzalez et al., 2020; Zou et al., 2025). In this fast-evolving landscape, academic proficiency alone is insufficient; learners must also exhibit resilience, adaptability, and a competitive edge across diverse conditions (Thornhill-Miller et al., 2023). Consequently, educational practices need to offer constructive spaces where students can cultivate vital 21st-century capabilities, including collaboration, communication, critical thinking, creativity, and citizenship (Bulkis et al., 2025). This imperative demands that educators structure contextual and meaningful learning environments capable of fostering active engagement among students (Shabrina & Astuti, 2022).

Among the core capabilities required in the modern era, creative thinking is vital for enabling learners to formulate novel ideas and resolve issues adaptively and innovatively (Stoeffler & Daley, 2023). Within physics education specifically, this skill empowers students to address contextual problems by proposing alternative remedies and implementing

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concepts in real-world scenarios (Yasiro et al., 2021; Karunaratne & Calma, 2024). Nevertheless, literature indicates that learners' creative thinking skills remain underdeveloped (Wafa et al., 2025). While many students can generate initial concepts, they frequently struggle when prompted to elaborate on or refine those thoughts with originality and depth. This deficiency is often rooted in conventional instructional methods that overemphasize teacher-led explanations instead of prompting students to independently explore, investigate, and construct knowledge (Hamdi et al., 2023).

To address this issue, learning approaches that are contextual, student-centered, and project-oriented are needed. One relevant topic in physics learning is alternative energy, which is closely related to current global issues such as the energy crisis and environmental sustainability (Yulna, 2025). One potential environmental project that can be integrated into physics learning is the utilization of banana peel waste as a bio-battery (Raharjo et al., 2025). Indonesia, as one of the world's largest banana producers, generates a considerable amount of banana peel waste, yet its utilization remains limited (Nisa et al., 2024; Alifah et al., 2022). The electrolyte content contained in banana peels enables them to be used as an alternative source of electrical energy (Pulungan et al., 2017). Integrating this environmental context into physics learning can help students understand concepts related to energy and electricity more concretely through real-world applications (Fikri et al., 2012; Arifia et al., 2025).

The implementation of contextual learning can be supported through interactive teaching materials such as e-LKPD. e-LKPD refers to an electronic student worksheet designed to support interactive and technology-assisted learning activities (Tantinta et al., 2025; Harmita et al., 2023). Utilizing e-LKPD prompts students to engage actively in autonomous concept discovery, thereby elevating their immersion throughout the educational process (Handayani et al., 2025). Furthermore, the integration of e-LKPD can be maximized when paired with the Project-Based Learning model anchored in STEM (PjBL-STEM). This combination offers genuine learning encounters via project tasks that require the interdisciplinary integration of science, technology, engineering, and mathematics (Jauhariyyah, 2017; Erlinawati et al., 2019). In this study, these goals are realized through the implementation of a project-based e-LKPD focused on banana peel waste processing within the PjBL-STEM framework. Such an approach is highly pertinent for nurturing active student inquiry, troubleshooting mechanisms, and innovative product generation.

Previous studies have demonstrated that project-based e-LKPD can positively support the enhancement of students' creative thinking skills (Raharjo et al., 2025). Nevertheless, research focusing on banana peel waste processing within STEM-integrated learning remains limited, particularly in relation to gender-based analysis. Furthermore, the application of contextual environmental project activities in physics learning has not been widely explored in promoting creative thinking skills. Therefore, this study examines the use of project-based e-LKPD implemented through the PjBL-STEM learning model in banana peel waste processing activities to analyze students' creative thinking development and describe gender-related differences.

METHOD

Research Design

This research applied a quasi-experimental method supported by interview data as complementary qualitative information. Quantitative data were used as the primary source for

examining the development of students' creative thinking skills after participating in physics learning activities conducted through project-based e-LKPD integrated with the PjBL-STEM learning model. In addition, qualitative findings provided deeper insight into students' responses and learning experiences throughout the implementation process.

The quantitative phase employed a one-group pretest-posttest approach involving two experimental classes with relatively comparable academic backgrounds. Both classes participated in learning activities using project-based e-LKPD focused on banana peel waste processing through the implementation of the PjBL-STEM model. The overall research design is presented in Table 1.

Table 1. Research Design Details for Quantitative Data

Group	Pretest	Treatment	Posttest
Grade X.1 (Experimental Class 1)	O ₁	X (learning activities through project-based e-LKPD on banana peel waste processing implemented within the PjBL-STEM learning model)	O ₂
Grade X.2 (Experimental Class 2)	O ₁	X (learning activities through project-based e-LKPD on banana peel waste processing implemented within the PjBL-STEM learning model)	O ₂

Description:

O₁ = Pretest of students' creative thinking skills

X = Learning activities through project-based e-LKPD on banana peel waste processing implemented within the PjBL-STEM learning model

O₂ = Posttest of students' creative thinking skills

The involvement of two experimental classes was intended to examine the consistency of students' improvement across different classroom environments with similar academic characteristics. Due to school regulations and classroom allocation limitations, this study was conducted without a control class. Therefore, the findings mainly describe students' learning improvement following the intervention rather than direct comparisons with conventional instruction.

The research procedure was conducted in three stages, namely preparation, implementation, and final analysis. During the preparation stage, preliminary observations were carried out, research permits were arranged, research instruments were developed, and validation procedures were completed. In the implementation stage, students in both experimental classes completed a pretest before participating in learning activities through project-based e-LKPD on banana peel waste processing implemented within the PjBL-STEM learning model. After the learning activities, students completed a posttest and several participants took part in interviews to provide information regarding their learning experiences. Finally, quantitative and qualitative findings were analyzed comprehensively to answer the research objectives.

Participants

The research focused on tenth-grade students at a state senior high school in Lampung, Sumatra, during the 2025/2026 academic year, where five classes made up the total population. Through a purposive sampling technique, two classes exhibiting highly similar characteristics, namely Class X.1 and Class X.2, were chosen. This selection was based on discussions with the physics teacher regarding academic performance, student engagement,

and general classroom dynamics. Serving as Experimental Class 1 and Experimental Class 2 respectively, each group contained 34 students, making a final sample size of 68 participants.

Instruments

To measure creative thinking skills, this study utilized an essay-based test administered during both pretest and posttest stages as the main instrument. The development of this test aligned with Torrance's framework, focusing on four specific indicators: fluency, flexibility, originality, and elaboration. It comprised five essay questions centered on projects involving alternative energy and banana peel bio-batteries, with every question structured to evaluate all four target indicators at once. Students were expected to evaluate scientific phenomena, formulate diverse concepts, offer varying perspectives on ideas, develop creative answers or designs, and logically expand on their explanations.

An analytical scoring rubric ranging from 0 to 4 for each dimension was employed to evaluate student answers. A zero core represented missing or off-topic replies, whereas a maximum score of 4 denoted exceptionally comprehensive, scientifically valid, original, and well-structured answers. Consequently, the upper limit for a single question was 16, with overall scores eventually transformed to a standard 0–100 scale. Table 2 outlines the overview of this evaluation rubric. An example of a test question is presented in Figure 1.

Table 2. Summary of Creative Thinking Skills Scoring Rubric

Indicator	Description	Score Criteria (0–4)
Fluency	Ability to generate multiple relevant ideas or solutions related to scientific problems	0 = no response; 1 = one irrelevant/limited idea; 2 = 2–3 relevant ideas; 3 = several relevant ideas; 4 = multiple relevant, scientifically accurate, and non-repetitive ideas
Flexibility	Ability to explain phenomena from different scientific perspectives	0 = no response; 1 = unclear explanation; 2 = one perspective explained correctly; 3 = two perspectives explained but less detailed; 4 = two or more scientifically correct and distinct perspectives
Originality	Ability to create unique ideas, designs, graphs, or innovative solutions	0 = no response; 1 = irrelevant response; 2 = simple/common idea; 3 = creative but general idea; 4 = unique, realistic, and scientifically appropriate idea/design
Elaboration	Ability to develop explanations systematically and in detail	0 = no response; 1 = very limited explanation; 2 = brief explanation; 3 = sufficiently detailed explanation; 4 = detailed, coherent, and scientifically connected explanation

Observe the comparison between zinc-carbon batteries and banana peel bio-batteries.

In a bio-battery, mashed banana peel paste serves as a substitute for the conventional electrolyte paste. Within a standard zinc-carbon battery, the zinc casing functions as the anode (-) and the carbon rod operates as the cathode (+), with the electrolyte paste acting as a medium to conduct ions. Conversely, the paste derived from banana peels naturally houses various ions, including potassium (K⁺), chloride (Cl⁻), sodium (Na⁺), magnesium (Mg²⁺), and manganese (Mn²⁺). The existence of these ions allows the banana peel mixture to act as an organic electrolyte capable of transmitting an electric current, positioning banana peels as an eco-friendly material for bio-batteries. Based on the information and illustration above, answer the following questions:

- Explain as many possible reasons as to why banana peels can be used as bio-batteries.
- Explain the phenomenon from two different perspectives: electrochemical reactions and electrical conductivity concepts.
- Create a simple design illustrating the role of banana peels in a bio-battery system.
- Choose one of your ideas and explain in detail how the bio-battery system works scientifically.

Figure 1. An Example of Creative Thinking Skills Test Question

Every test item was designed to simultaneously assess students' capacity for originality, fluency, elaboration, and flexibility. Prior to its deployment in the main study, a pilot test was administered to students who had already studied the related topics. To evaluate item validity, the Pearson Product-Moment correlation was applied, while Cronbach's Alpha was selected to measure internal consistency. The validity assessment yielded Pearson correlation coefficients ranging from 0.45 to 0.92, indicating that the entire instrument ranged from sufficiently to highly valid. Additionally, the reliability testing resulted in a Cronbach's Alpha coefficient of 0.80, confirming the tool's high reliability and its suitability for research purposes.

Data Analysis

Statistical methods encompassing both descriptive and inferential analyses were performed through SPSS 27 to evaluate the quantitative data. The descriptive approach aimed to compute the mean, maximum and minimum scores, alongside tracking the enhancement of students' creative thinking skills following the use of project-based e-LKPDs integrated with the PjBL-STEM model. To assess the growth between pretest and posttest evaluations, the normalized gain (N-Gain) test was implemented. The specific classification criteria used to interpret these N-Gain scores can be found in Table 3.

Table 3. N-Gain Classification

Average N-Gain	Classification
$(g) > 0.70$	High
$0.30 \leq (g) \leq 0.70$	Medium
$(g) < 0.30$	Low

(Meltzer, 2002)

Prior to executing the hypothesis testing, the Kolmogorov–Smirnov method was utilized to check the normality of the data distribution, applying a 0.05 significance threshold. The dataset was deemed normally distributed provided that the resulting p-value exceeded 0.05. Subsequently, a paired-sample t-test was employed to assess if a significant shift occurred between the pretest and posttest marks following the deployment of PjBL-STEM-driven project e-LKPDs.

Furthermore, an independent-sample t-test was executed to explore potential disparities in N-Gain outcomes between male and female students. To satisfy the prerequisite for this independent t-test, Levene’s Test was first carried out to evaluate variance homogeneity. Homogeneous conditions were confirmed if the significance value was higher than 0.05. Meanwhile, the qualitative insights gathered from interviews were processed descriptively using a framework of data reduction, data display, and drawing conclusions. These qualitative themes served to reinforce and contextualize the quantitative evaluation regarding students’ creative thinking achievements and learning journeys throughout the PjBL-STEM project implementation.

RESULTS AND DISCUSSION

Results

Quantitative Findings

Statistical analysis indicated that integrating project-based e-LKPDs via the PjBL-STEM model fostered a positive development in students’ creative thinking skills within both experimental groups. An assessment of the N-Gain metrics demonstrated that the average improvement in these creative thinking skills reached the high category. For a detailed breakdown of these N-Gain values, refer to Table 4.

Table 4. Results of the N-Gain Calculations for Creative Thinking Skills in Each Class

Group	Class Score		
	Highest N-Gain	Lowest N-Gain	Average N-Gain
Experimental Class 1	0.93 (High)	0.53 (Medium)	0.72 (High)
Experimental Class 2	0.92 (High)	0.59 (Medium)	0.75 (High)

As displayed in Table 4, a high level of growth in creative thinking skills was achieved by both experimental classes. These outcomes demonstrate that PjBL-STEM learning experiences utilizing project-based e-LKPDs centered on banana peel waste management played a positive role in boosting students’ creative thinking skills. Even though Experimental Class 2 recorded a marginally higher mean N-Gain score compared to Experimental Class 1, the overall progress across both groups remained relatively comparable.

Additionally, enhancements in students’ creative thinking skills were clearly observed across all evaluated indicators, namely flexibility, fluency, elaboration, and originality. A comprehensive breakdown of the N-Gain scores for each specific indicator is presented in Figure 2.

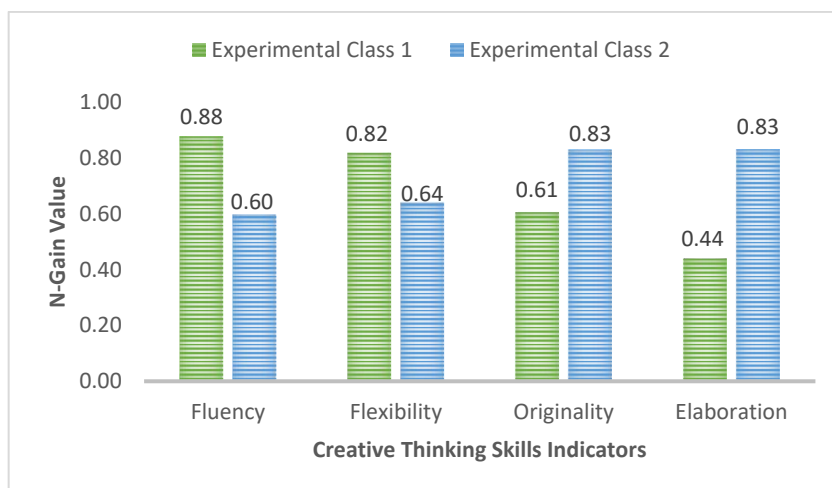


Figure 2. N-Gain Creative Thinking Skills for Each Indicator

Based on Figure 2, differences in improvement were found across the creative thinking indicators in both classes. Experimental Class 1 showed higher improvement in the fluency and flexibility indicators, whereas Experimental Class 2 demonstrated higher improvement in originality and elaboration. Nevertheless, all indicators in both classes were categorized as high, indicating that the learning activities successfully facilitated various aspects of students' creative thinking skills.

To fulfill the assumptions required for hypothesis testing, data distribution was verified via the One-Sample Kolmogorov-Smirnov method. The outcomes of this preliminary evaluation are detailed in Table 5. Based on Table 5, the calculated significance levels for both the pretest and posttest in Experimental Class 1 and Experimental Class 2 are strictly above 0.05. Such a finding implies that the research data conforms to a normal distribution, satisfying the essential assumption for parametric analysis. To subsequently examine if the variances between the investigated groups were homogeneous, Levene's Test was carried out. The summary of this variance evaluation is provided in Table 6.

Table 5. Normality Test of Research Data

Instrument	Experimental Class 1		Experimental Class 2	
	Sig	Interpretation	Sig	Interpretation
Pretest	0.08	Normal	0.08	Normal
Posttest	0.20	Normal	0.20	Normal

Table 6. Homogeneity Test of Research Data

	Levene Statistic	df1	df2	Sig
Based on Mean	1.220	3	132	0.305
Based on Median	1.215	3	132	0.307
Based on Median and with Adjusted df	1.215	3	122.026	0.307
Based on Trimmed Mean	1.235	3	132	0.300

Based on Table 6, the homogeneity test showed a significance value of 0.305 (> 0.05), indicating that the data variances between the groups were homogeneous. To evaluate the

impact of the educational intervention, a paired-samples t-test was executed to analyze changes between students' initial pretest and final posttest performances. The statistical outcomes of this analysis are detailed in Table 7.

Table 7. Results of the Paired-Sample T-test

	N	Mean	Std.Dev	sig. (2-tailed)
<i>Pretest_Experimental Class 1</i>	34	37.39	6.33	< 0.001
<i>Posttest_Experimental Class 1</i>	34	82.50	6.89	
<i>Pretest_Experimental Class 2</i>	34	35.18	4.92	< 0.001
<i>Posttest_Experimental Class 2</i>	34	83.64	6.43	

The quantitative indicators compiled in Table 7 demonstrate that the paired-sample t-test yielded a significant post-intervention enhancement in both experimental groups. Specifically, Experimental Class 1 experienced an upward shift in its mean score from 37.39 during the pretest to 82.50 in the posttest phase. Meanwhile, Experimental Class 2 recorded a parallel surge, with its average performance ascending from 35.18 to 83.64. Given that the corresponding significance value fell below the 0.05 threshold (Sig. < 0.001), a statistically meaningful disparity between the pretest and posttest measurements is confirmed. These outcomes strongly imply that executing physics lessons through project-based e-LKPDs via the PjBL-STEM framework effectively advanced the students' creative thinking skills.

Moreover, an independent-samples t-test was utilized to determine if gender-specific variations had an effect on the advancement of students' creative thinking skills. The empirical data derived from this gender-focused evaluation are presented in Table 8.

Table 8. Results of the Independent Samples T-Test by Gender

	N	Mean	Std. Dev	Sig. (2-tailed)
Male	33	0.72	0.11	0.35
Female	35	0.74	0.09	0.36

Based on the statistical outputs displayed in Table 8, the significance values derived from the independent-samples t-test were higher than the 0.05 threshold. This statistical output confirms that no meaningful disparity exists regarding creative thinking skill enhancements between male and female participants. Even though minor descriptive variances were identified when looking at individual indicators, these discrepancies failed to reach statistical significance. A visual representation of these descriptive variances is provided in Figure 3.

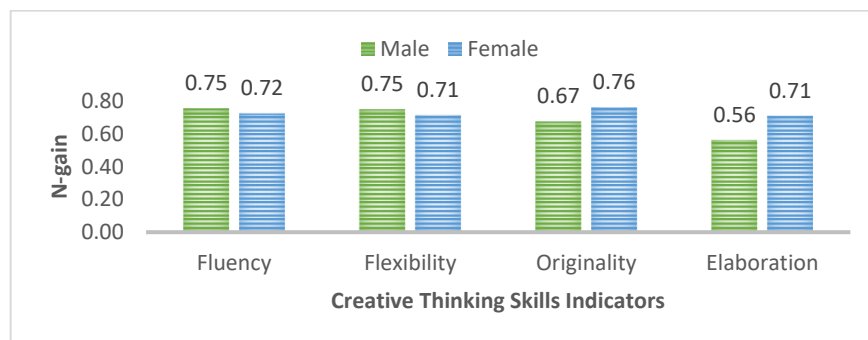


Figure 3. Comparison of N-Gain for Each Creative Thinking Skills Indicator by Gender

Based on Figure 3, descriptive differences were observed across several indicators of creative thinking skills. Male students showed slightly higher scores in fluency and flexibility, whereas female students showed slightly higher scores in originality and elaboration. However, these differences were not statistically significant.

Qualitative Findings

The quantitative outcomes are further supported by qualitative data, which demonstrated progress in students' creative thinking skills after engaging with the STEM-focused project-based e-LKPD centered on recycling banana peel waste. Through a thematic analysis of classroom observations, student interviews, and feedback gathered during the instructional sessions, various insights emerged regarding learners' educational experiences, collaborative efforts, engagement levels, and conceptual exploration.

Student Engagement

Most students reported that the learning activities were more interesting because they were directly involved in conducting experiments and developing bio-battery projects from banana peel waste. Students felt more motivated to participate actively because the learning process was connected to real-life environmental issues. A student stated: *"I became more enthusiastic because we did not only study theories, but also directly created a project from banana peel waste. It made physics learning more interesting and easier to understand."* Another student explained: *"Usually physics only focuses on formulas, but this project made me more active in discussing and trying new ideas with my group."* These findings indicate that contextual project-based learning encouraged students' active participation and increased their interest in learning physics.

Collaboration and Active Participation

During the project activities, students actively exchanged ideas and collaborated in designing bio-battery products. The learning process provided opportunities for students to express different perspectives and develop creative solutions together. A student commented: *"Each group member had different ideas about how to improve the bio-battery design, so we discussed and combined our ideas together."* Another student stated: *"We tried several ways to make the bio-battery work better. Sometimes our first idea failed, but we continued improving it."* These responses suggest that the implementation of project-based e-LKPD facilitated collaborative learning and supported students in exploring and developing creative ideas throughout the project activities.

Idea Exploration and Creative Thinking Development

Students also demonstrated active exploration of ideas throughout the project activities. They tried various approaches in designing and improving banana peel bio-battery products, including modifying materials and testing different arrangements to produce electrical energy. According to students' responses, the learning activities encouraged them to think more creatively, develop unique ideas, and explain their reasoning in greater detail. *"At first, we were confused and unsure whether the bio-battery would work or not, but after trying it, it successfully turned on the LED light. It was very exciting."* This finding suggests that hands-on project experiences encouraged students to think creatively and develop originality and elaboration skills through direct experimentation and problem-solving activities. Beyond merely conceiving initial concepts, learners demonstrated the capacity to expand, refine, and articulate their

thoughts with greater depth and systematic clarity throughout the project execution and presentation phases.

On the whole, qualitative observations indicate that the integration of PjBL-STEM-integrated e-LKPDs succeeded in cultivating an interactive, contextualized, and learner-focused environment. Such an instructional setting directly reinforced the growth of creative thinking skills among participants.

Discussion

The empirical evidence gathered in this investigation demonstrates that project-oriented e-LKPDs focused on banana peel waste processing, implemented within the PjBL-STEM learning model, exerted a highly positive influence on advancing students' creative thinking skills. This enhancement is explicitly confirmed by the high N-Gain marks recorded across both experimental classrooms, alongside the substantial divergence observed between the pretest and posttest measurements following the pedagogical intervention. These outcomes strongly indicate that the structured coursework effectively stimulated the core indicators of creative thinking skills, specifically flexibility, fluency, originality, and elaboration through hands-on, project-based experimental milestones.

The improvement in fluency skills was reflected in students' ability to generate multiple ideas and possible solutions during project discussions and experimental activities. During the project planning phase, students actively discussed possible materials, experimental procedures, and strategies to improve the electrical output of banana peel bio-batteries. These activities encouraged students to produce various relevant ideas and alternative solutions to the given scientific problems. This finding indicates that project-based learning activities can facilitate idea generation through collaborative and contextual problem-solving processes (Saefullah et al., 2021).

Flexibility skills were developed when students explained the bio-battery phenomenon from different scientific perspectives, particularly electrochemical reactions and electrical conductivity concepts. Students were not only required to identify the role of ions in banana peel paste as natural electrolytes but also to connect the phenomenon with electrical current flow and battery components. This process encouraged students to analyze scientific phenomena using different conceptual approaches

The improvement in originality skills was observed during the design and experimentation stages. Several student groups proposed different bio-battery designs, electrode arrangements, and experimental modifications to improve the voltage produced by the bio-batteries. Instead of passively replicating instructor-led demonstrations, learners actively investigated unique concepts and verified alternative setups throughout the experimental workflow. These structured tasks offered a valuable framework for learners to cultivate innovative and divergent thinking pathways by navigating real-world troubleshooting scenarios. This outcome aligns with the documentation by Suprpto et al. (2024), which emphasizes that project-centered tasks stimulate active peer collaboration and the resolution of intricate challenges to yield concrete artifacts.

Meanwhile, elaboration skills were reflected in students' ability to systematically develop project plans, prepare scientific posters, explain experimental procedures, and present project findings in detail. Students were required to organize ideas coherently from the planning stage to the final presentation, which encouraged them to elaborate scientific explanations more comprehensively.

The qualitative findings further supported the quantitative results by showing that students experienced increased curiosity, learning motivation, and active participation during the learning activities. Interview results revealed several recurring themes, including increased learning motivation, active exploration of ideas, and meaningful hands-on learning experiences. A student stated: *"The learning was really fun. I just found out that banana peels can be used as bio-batteries. Previously, I thought banana peels were only waste, but it turns out they can also be used as an energy source."* This feedback demonstrates that anchoring learning activities within contextual environmental issues enabled students to bridge theoretical physics principles with tangible real-world phenomena, thereby rendering the educational experience significantly more profound and captivating. Another student explained: *"This was our first time making a project like this. At first, we were confused and unsure whether the bio-battery would work, but after testing it and seeing the LED light turn on, it became very exciting."* This finding suggests that direct experimental involvement and hands-on project activities increased students' enthusiasm and confidence during learning. Meaningful learning experiences and active participation also contribute positively to students' learning motivation (Brophy, 2010; Saleh, 2014).

In terms of gender-related variations, descriptive data indicated that male students achieved marginally superior marks on the fluency and flexibility parameters, whereas female learners registered slightly higher performance on the originality and elaboration dimensions. Nonetheless, the independent-samples t-test demonstrated that these descriptive discrepancies did not yield a statistically significant variation regarding the overall enhancement of creative thinking skills between the two groups. Consequently, these marginal differences must be analyzed with care and should not be used to generalize gender-based cognitive gaps in creative thinking skills.

On the whole, the evidence reveals that utilizing project-based digital worksheets, implemented through the PjBL-STEM model, successfully yielded purposeful and real-world learning milestones that nurtured creative thinking skills. By engaging in collaborative brainstorming, hands-on trials, design modeling, and scientific defense sessions, participants were deeply involved in constructing insights, managing contextual crises, and designing innovative answers to ecological and renewable energy dilemmas.

While the outcomes demonstrate clear educational benefits, certain methodological constraints within this investigation warrant recognition. Primarily, the research utilized a purposive sampling approach restricted to a confined sample size comprising only two academic classes. Consequently, the empirical insights derived from this setup might possess constrained generalizability. In addition, the use of repeated pretest and posttest measures may have introduced possible testing effects, as students could become familiar with the question formats and assessment procedures during the study. This familiarity may have influenced students' posttest performance to some extent. Furthermore, creative thinking skills in this study were primarily measured through written essay-based assessments. Although the instruments were designed to assess fluency, flexibility, originality, and elaboration, written tests alone may not fully capture students' creative thinking performance during collaborative discussions, project activities, and hands-on experimentation processes. Therefore, future studies are recommended to involve larger and more diverse samples and employ more comprehensive assessment methods such as observations, portfolios, performance-based assessments, and classroom interaction analyses to obtain a deeper understanding of students' creative thinking skills in project-based STEM learning contexts.

CONCLUSION

Conclusively, the empirical outcomes indicate that electronic student worksheets centered on banana peel waste management, implemented within the PjBL-STEM learning model, hold substantial promise for cultivating students' creative thinking skills. The observed growth in pretest-to-posttest performance, coupled with high N-Gain metrics, reflects that these contextual, hands-on learning activities successfully fostered the core indicators of flexibility, fluency, elaboration, and originality. Regarding gender analysis, no statistically meaningful differences emerged between male and female participants, despite minor descriptive fluctuations across specific criteria. These outcomes indicate that utilizing environmental project-based e-LKPDs offers a viable alternative approach to support creative thinking in physics instruction. Nonetheless, since this research lacked a control group for comparison, the evidence of its direct efficacy should be approached with caution and cannot be generalized as definitive causal evidence.

This investigation is subject to certain boundaries, notably the lack of a control cohort and the reliance on purposive sampling inside a restricted school setting. Accordingly, future research endeavors should consider utilizing expanded sample volumes, adopting comparative experimental frameworks, and investigating the enduring educational impact of project-driven e-LKPD implementation on students' creative thinking skills along with other vital 21st-century capabilities.

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