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Banana Peel Bio-Battery Project-Based Electronic Worksheet: Enhancing Creative Thinking and Psychomotor Skills

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This study aims to develop a project-based electronic student worksheet on banana peel bio-battery (hereinafter referred to as a project-based e-LKPD) to process banana peel waste into a simple bio-battery and to examine its validity, practicality, and effectiveness in improving students' creative thinking and psychomotor skills. The product was developed using the 4D model (Define, Design, Develop, Disseminate) and grounded in Social Constructivism theory. It was tested on 15 Grade X high school students. Validation by material, media, and learning experts yielded an average score of 3.29 (on a 1–4 scale), indicating very good quality in terms of content and instructional design. Practicality was assessed through readability (97%), student questionnaire responses (95%), and teacher perceptions (88.09%), confirming that the project-based e-LKPD is easy to use, well-received, and allows students to complete project tasks with minimal difficulty. The effectiveness test showed an average score of 82.1 for creative thinking skills and 75.2 for psychomotor skills (both on a 0–100 scale), demonstrating significant improvement in both competencies. These results confirm that the project-based e-LKPD on banana peel bio-battery is valid, practical, and effective as an innovative learning tool to promote higher-order thinking, hands-on skills, environmental awareness, and understanding of renewable energy.

Keywords: Project Based Learning; Student Worksheet; Creative Thinking Skills; Psychomotor Skills; Renewable Energy

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INTRODUCTION

The global energy crisis and environmental impacts of fossil fuel dependence have encouraged the development of renewable alternatives. Agricultural and household waste offers significant potential as a sustainable energy source while contributing to waste reduction (Nusantoro & Awaludin, 2020). Among these, banana peel waste is abundant in Indonesia and contains minerals such as potassium and chloride, wich can be processed into electrolytes for bio-battery applications (Fadhallah et al., 2022). This positions banana peel waste as promising material for integrating waste management and renewable energy education.

Recent studies have explored various uses of banana peel waste, primarly in food products, while its potensial in energy generation remains underutilized (Anwar et al., 2021; Fatimah et al., 2023). In educational settings, processing banana peels into bio-batteries provides an authentic project activity that can strengthen students conceptual understanding while fostering creative and psychomotor skills. Project Based Learning (PjBL) enables this integration by engaging students in real world problem solving (Riastuti & Febrianti, 2021; Markula & Aksela, 2022). Digital scaffolding through electronic worksheets (e-LKPD) further supports differentiated learning needs by incorporating principles of Vygotsky Zone of Proximal Developmnet (ZPD) (Ness, 2022).

However, although e-LKPDs are widely developed, no existing studies have integrated PBL-based digital scaffolding with bio-battery production using banana peel waste. Prior research introduces eco-themed project worksheets (Wahyuni et al., 2020), yet none combine renewable energy generation, waste processing, and digital scafoldng within a single instructional product. This forms a clear research gap in both renewable energy education and digital R&D product development. The novelty of this study therefore lies in designing an e-LKPD that embeds bio-battery project activities to simultaneously promote creative thinking and psychomotor performance.

Preliminary observations involving six teachers and 131 students across five schools in Lampung Province revealed limited learning media for alternative energy topics and low student exposure to waste-based energy projects. More than 80% of students reported never working with waste materials in physics learning, indicating a strong need for innovative and contextual learning resources. Findings from recent meta-analyses also confirm that Project-Based Learning (PBL) effectively enhances higher-order thinking skills and student engagement (Zhang & Ma, 2023; Guo et al., 2020). However, no existing e-LKPD integrates banana peel bio-battery content with PBL scaffolding, creating a clear gap in available instructional materials. Responding to this gap, this study aims to develop a project-based e-LKPD on banana peel waste processing to enhance students' creative thinking and psychomotor skills within the alternative energy topic.

METHOD

The research methodology employed in this study was development research using the 4D model (Define, Design, Develop, and Disseminate) by (Thiagarajan, 1974). The e-LKPD was designed based on constructivist principles, incorporating structured scaffolding, guided prompts, formative feedback, and peer collaboration to support inquiry-based and reflective learning. Social constructivist elements were integrated to facilitate collaborative knowledge construction through discussion and group problem-solving. The product was tested on 15 Grade X students from SMA IT Ar-Raihan, Bandar Lampung, selected using simple random sampling. All Grade X students were assigned numbers, and 15 were chosen through a lottery draw to ensure unbiased selection. Although the sample size is small and limits statistical generalization, it is appropriate for early-stage product development focused on formative evaluation, and future studies with larger samples are recommended to enhance generalizability.

Instrument development was conducted during the Define and Develop stages. Expert validation involved two physics education lecturers and one physics teacher, who evaluated the e-LKPD using a 4-point Likert rubric covering the aspects of media and design quality as well as material and construct quality, with indicators assessing relevance, clarity, alignment, accuracy, and coherence. Reliability testing such as Cronbach's Alpha was not performed because this early-stage study prioritized expert-based content validation. Practicality was assessed through readability tests, teacher responses, and student questionnaires. Effectiveness was measured using performance rubrics for creative-thinking and psychomotor skills. The creative-thinking rubric was developed based on Torrance's indicators of fluency, flexibility, originality, and elaboration, while the psychomotor rubric was adapted from (Wijayanti, 2020), encompassing students' ability to prepare and use tools and materials, follow demonstration procedures accurately, execute experimental steps, operate and test the product, record experimental results, and present their findings. Ethical approval was obtained from the participating school, and all students provided informed consent prior to data collection.

Data obtained from each test were analyzed using different techniques.

1. Data Analysis Technique for Validity

The validity data were obtained from expert validation questionnaires, including material and construction experts as well as media and design experts, which were filled out by the validators. The validity criteria were determined through expert validation tests, and the data analysis technique used the results of the expert validation test calculated using the following formula.

$$p = \frac{Average\ Score}{\sum Total}$$

The calculation results are then interpreted to determine the quality of the developed product. The score interpretation is adapted from Ratumanan & Laurent (2011), and the details can be seen in Table 1.

[Table 1 about here.]

2. Data Analysis Technique for Practicality

The data analysis for practicality is intended to determine the practicality of the product, which is obtained based on the completion of questionnaires. The results are analyzed using percentages based on the formula.

$$\%X = \frac{\sum score\ obtained}{\sum maximum} 100\%$$

The data from the questionnaire responses are analyzed using percentages, as adapted by (Arikunto, 2011), and the details can be seen in Table 2.

[Table 2 about here.]

3. Data Analysis Technique for Effectiveness

The data analysis for effectiveness is conducted to assess the development of students' creative thinking skills and psychomotor skills. The analysis is carried out using the following formula

$$NP = \frac{\sum NI}{SM} \times 100\%$$

Description:

NP = the value sough

$\sum NI$ = number of indicators that appear

SM = total maximum score of indicators

In addition to computing the overall effectiveness score, indicator-level analysis was also conducted. For creative thinking, scores for fluency, flexibility, originality, and elaboration were analyzed separately. For psychomotor performance, each indicator in the rubric was examined individually. Mean and standard deviation were calculated to evaluate variability and identify specific strengths and weaknesses within the skill components. This approach provides a more comprehensive interpretation of student performance beyond the overall score.

The obtained score is converted into categories for assessing creative thinking skills and psychomotor skills. The assessment categories can be seen in Table 3.

[Table 3 about here.]

RESULT AND DISCUSSION

Result

This development research produces a product in the form of an e-LKPD based on a banana peel waste processing project to train valid, practical, and effective creative thinking skills and psychomotor skills.

a. Validity Test

Product Validation of e-LKPD

The validation of the e-LKPD product was conducted by three experts, consisting of two Physics Education lecturers from the University of Lampung and one high school Physics teacher. The validation of the e-LKPD consists of two categories: media and design aspects, and material and construction aspects. The results of the product validity can be seen in Table 4.

[Table 4 about here.]

Empirical Test of Bio-Battery

The empirical test of the bio-battery is conducted to determine the voltage and current generated by the bio-battery, as well as its durability. This testing is done using pure banana peel waste and banana peel with the addition of a salt solution. The data from the test results can be seen in Table 5.

[Table 5 about here.]

b. Practicality Test

The practicality of the project-based e-LKPD developed refers to how effectively and efficiently the e-LKPD is used in practice in the classroom. The practicality evaluation consists of readability tests for students, student response questionnaires, and teacher perception tests for teachers. The readability questionnaire is filled out by a small group of 15 students who have completed the developed e-LKPD. The teacher perception test was filled out by 7 teachers from 6 schools in Lampung. The student response questionnaire, after completing the developed e-LKPD, was then filled out by a small group consisting of 15 students. Below is a summary of

the Practicality test results, where the answers to the questionnaire are analyzed and then categorized according as shown in Table 6.

[Table 6 about here.]

c. Effectiveness Test

The assessment results of the e-LKPD for training creative thinking skills and psychomotor skills are evaluated based on the achievement of the creative thinking skill indicators according to Torrance. The results can be seen in Table 7.

[Table 7 about here.]

[Figure 1 about here.]

The results of the assessment of psychomotor skills are adapted from (Wijayanti, 2020). The results can be seen in Table 8.

[Table 8 about here.]

[Figure 2 about here.]

Discussion

The implementation of the project-based e-LKPD for banana waste processing has proven to be effective in developing students creative thinking and psychomotor skills. The result obtained form the validity, practicality, and effectiveness tests provide strong evidence that the developed product is feasible for classroom use.

a. Validity

The expert validation results show that both the media–design aspects and the material–construction aspects fall into the valid to very valid categories. This indicates that the e-LKPD meets key standards of instructional design, including clarity, content alignment, accuracy, coherence, and usability. These findings are consistent with recent studies stating that learning materials are considered valid when they demonstrate strong alignment between objectives, content, and learning activities (Nusantoro & Awaludin, 2022).

The high validation score in the design aspect also suggests that the layout, structure, readability, and visual components effectively support student learning. This agrees with recent instructional development research highlighting the importance of well-designed digital materials in enhancing student engagement and comprehension (Hollil et al., 2022).

b. Practicality

The practicality results show excellent responses from both students and teachers, with an overall average score of 93.33%. The readability score (97%) indicates that students find the e-LKPD easy to understand, accessible, and engaging. The integration of digital media such as smartphones and laptops also increases its practicality and relevance to students' learning habits. This is supported by (Safarati et al., 2022), who found that digital learning materials significantly increase student motivation and participation.

Teachers also gave very positive evaluations, indicating that the e-LKPD is feasible for implementation across different school contexts. This aligns with findings showing that digital project-based materials are practical because they simplify instructional delivery and support flexible, student-centered learning environments (Mutanga, 2024).

c. Effectiveness of Creative Thinking Skills

Based on Torrance's indicators, students' creative thinking skills fall within the trained to well trained categories. High scores in fluency and flexibility show that students can generate multiple ideas and consider diverse perspectives during problem identification and project planning. This supports (Oktaviani & Supriyadi, 2024), who reported that student curiosity plays a significant role in enhancing creative thinking.

However, the originality and elaboration indicators show lower achievement. Students could propose ideas, but many struggled to elaborate them in a systematic and detailed manner. This aligns with (Irman et al., 2025), who found that students often find it difficult to develop unique and well-structured ideas without sufficient guidance. Recent studies also emphasize that effective scaffolding and teacher facilitation can significantly enhance creativity and idea development (Adeline, 2024; Li & Tu, 2024).

Thus, improvements in the e-LKPD's instructional guidance, especially clearer examples, prompts for deeper elaboration, and structured planning support—would help strengthen students' originality and elaboration skills.

d. Effectiveness of Psychomotor Skills

The assessment results show that students' psychomotor skills are generally well-developed, with an overall score of 75.2%. The highest achievement (83.3%) appears in the indicator of preparing tools and materials, consistent with (Safarati et al. 2022), who state that proper preparation is essential for effective practicum activities.

The lowest score is found in the indicator of using tools and materials (61.6%), suggesting that students still require additional practice using scientific equipment such as multimeters and bio-battery components. Limited laboratory experience is known to reduce students' proficiency in handling scientific instruments (Safarati et al., 2022).

Students also showed challenges in assembling circuits accurately, which is consistent with the findings of (Keliata & Choirunnisa, 2023), who emphasize that teacher scaffolding is

crucial when students engage in complex procedural tasks.

Meanwhile, indicators related to operating, testing, and recording experiment results received moderate scores. Students could follow experimental procedures but encountered difficulties in interpreting and documenting results systematically. This supports (Shulkhah, 2020), who found that analytical skills are essential for identifying errors and making sense of experimental outcomes.

CONCLUSION

Based on the results and discussion, it can be concluded that the project-based e-LKPD developed in this study is highly valid, practical, and effective for enhancing students' creative thinking and psychomotor skills. Expert validation yielded an overall score of 3.29 (very valid), with media and design aspects scoring 3.36 (very valid) and material and construction aspects scoring 3.22 (valid). These results indicate that the e-LKPD, focused on banana peel waste processing, is suitable for implementation in physics learning, particularly on alternative energy topics.

The e-LKPD also demonstrated high practicality in classroom use, as reflected in the readability test (97%), student responses (95%), and teacher perceptions (88.09%), all categorized as "very practical." This suggests that the e-LKPD is accessible, engaging, and user-friendly for both students and teachers. Furthermore, the project activities promoted greater student engagement, environmental awareness, and collaborative learning, indicating potential long-term behavioral benefits beyond immediate learning outcomes.

Effectiveness assessment shows that students achieved an average creative thinking score of 83.13% (highly trained) and an average psychomotor skill score of 77.61% (trained). The integration of digital reporting tools also contributed to enhancing students' digital literacy and reflective practices.

However, the study has limitations, including a small sample size and a short implementation period, which may affect the generalizability of the results. Future research should involve larger and more diverse populations, extend the intervention period, and incorporate more structured digital scaffolding to further support originality and systematic elaboration in student thinking**.** In addition, the developed e-LKPD is recommended for adoption as supplementary material for Class X on alternative energy.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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TABLE 1 / Conversion of Validity Assessment Scores for the Product

Score Interval of Research Result	Criteria
3,25< skor <4,00	Very Valid
2,50< skor <3,25	Valid
1,75< skor <2,50	Less Valid
1,00< skor <1,75	Not Valid

TABLE 2 / Conversion of Practicality Assessment Scores for the Product

Persentase	Criteria
0,00% - 20%	Very Low Practicality/ Not Good
20,1% - 40%	Low Practicality / Fairly Poor
40,1% - 60%	Moderate Practicality / Fairly Good
60,1% - 80%	High Practicality / Good
80,1% - 100%	Very High Practicality / Very Good

TABLE 3 / Conversion of Effectiveness Assessment Scores for the Product

Persentase	Criteria
0,00%-20%	Not Trained
20,1%-40%	Poor Trained
40,1%-60%	Moderately Trained
60,1%-80%	Trained
80,1%-100%	Well Trained

TABLE 4 / The Average Score Results of Expert Testing

Aspect		Validator			Average Score	Category
		1	2	3		
Media and Design Validation	Cover	3,22	3,00	3,66	3,29	Very Valid
	Content	3,20	3,60	3,50	3,43	Very Valid
Material and Construction Validation	Content Suitability	3,00	3,00	3,37	3,12	Valid
	Construction	3,14	3,28	3,57	3,31	Very Valid
Average/expert		3,14	3,22	3,52		
Overall Average					3,29	Very Valid

TABLE 5 / Result Empirical Test of Bio-Battery

Waste	Additional Material	Result		
		Time	Voltage (V)	Electric Current (A)
Banana peel (Muli variety)	None	1 day	1,22	0,53
		2 days	1,19	0,48
		3 days	1,21	0,51
Banana peel (Muli variety)	NaCl salt solution	1 days	1,13	0,47
		2 days	1,12	0,51
		3 days	1,08	0,49

TABLE 6 / Result Practicality Test

No	Aspect	Percentage	Category
1	Readability	97%	Very Good
2	Student Response	88,09%	Very Good
3	Teacher Perception	95%	Very Good
	Overall Percentage Average	93,33%	Very Good

TABLE 7 / The Results of the Achievement of Creative Thinking Skill Indicators

No	Indicators Creative Thinking Skills	Total Score	Total Skor Maxsimum	% Average Score	Category
1	*Fluency*	162	180	90%	Well Trained
2	*Flexibility*	102	120	85%	Well Trained
3	*Originality*	279	360	77,5%	Trained
4	*Elaboration*	183	240	76,25%	Trained
	Average			82,1%	Well Trained

TABLE 8 / The Result of the Achievement of Psychomotor Skills

No	Indicatiors Psychomotor Skills	Total Score	Total Skor Maximum	%	Categori
1	Preparing tools and materials	50	60	83,3%	Well Trained
2	Using tools and materials	37	60	61,6%	Trained
3	Demontrating accuracy in assembling and building the project	51	60	68,3%	Well Trained
4	Executing the experimental procedure	45	60	75%	Trained
5	Operating and testing the procedure	46	60	76,6%	Trained
6	Recording experimental result	44	60	73,3%	Trained
7	Presenting the project result	53	60	88,3%	Well Trained
	Total Score	326	420	75,2%	Trained

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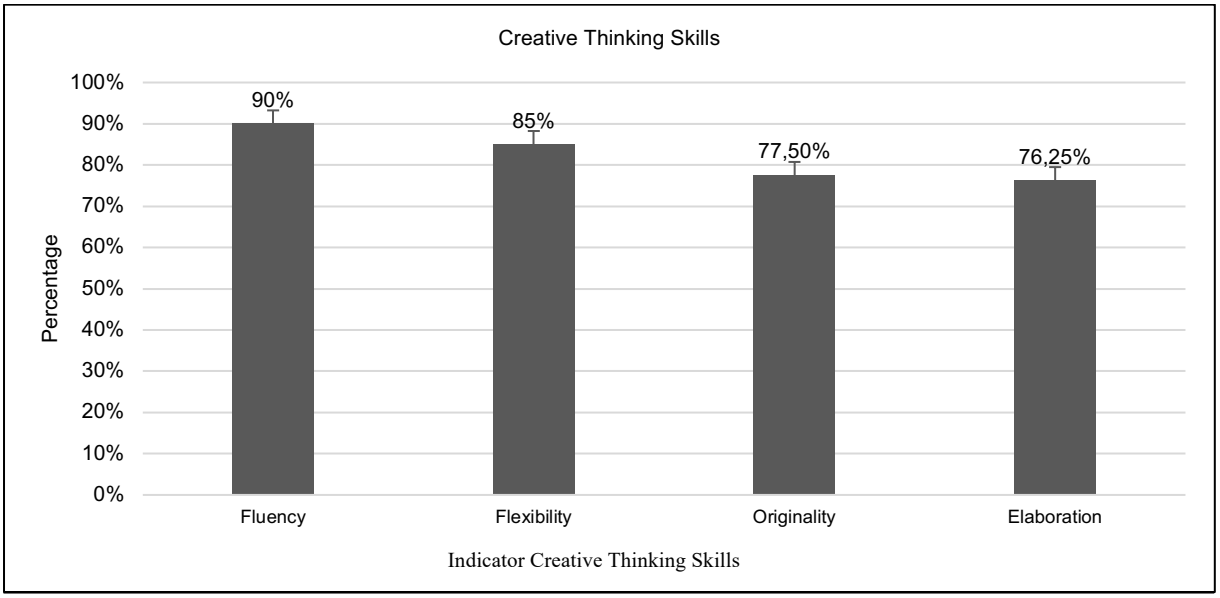

FIGURE 1 / Percentage Indicator Creative Thinking Skills

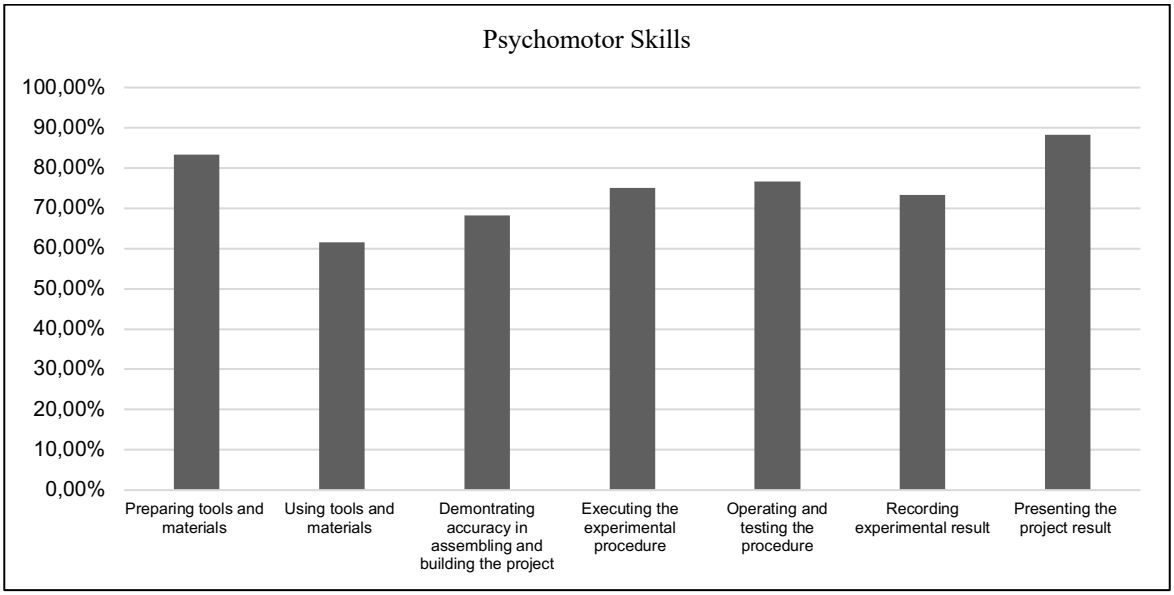

FIGURE 2 / Percentage Indicator Psychomotor Skills