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Development of a Project-Oriented Biotechnology Worksheet to Enhance Creativity Among Upper-Secondary Students

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Abstract

Background: Biotechnology learning at the upper-secondary level is still predominantly theoretical, lacks contextual relevance, and provides limited opportunities for students to develop creativity. A preliminary study conducted prior to this research confirmed that students' creative thinking abilities were below the expected threshold, with an average pre-intervention score of 37.60 out of 100, indicating an urgent need for creativity-focused instructional materials. Therefore, instructional materials are needed that encourage active student engagement through project-based activities that allow the development of ideas in terms of fluency, flexibility, originality, and elaboration.

Methods: This study aimed to develop a project-oriented biotechnology student worksheet (LKPD) to enhance the creativity of upper-secondary students using the Four-D (4D) development model consisting of the Define, Design, Develop, and Disseminate stages. The Define stage involved needs analysis, curriculum review, and literature study. The Design stage produced an initial LKPD prototype containing project-based learning activities aligned with the Merdeka Curriculum. In the Develop stage, the worksheet underwent expert validation as well as practicality and effectiveness testing with students.

Results: The expert validation results indicated a very high level of validity with a Content Validity Index (CVI) of 0.895. The practicality test involving 30 students yielded a score of 85.33%, categorized as Practical. Student response questionnaires separately showed an average score of 92.70% (Very Good), reflecting positive perceptions regarding the clarity of instructions, ease of use, and relevance of the projects. The effectiveness test used a one-group pretest–posttest design with a creativity instrument adapted from the Torrance Test of Creative Thinking. The results showed a significant improvement, with the average pretest score increasing from 37.60 to 75.87 and an overall N-Gain value of 0.61 (moderate category). Notably, originality achieved an N-Gain of 0.76 (High) and fluency achieved 0.72 (High), while flexibility and elaboration each reached 0.58 (Medium). The Wilcoxon Signed

Ranks Test yielded a significance value of 0.000 (< 0.05), indicating a statistically significant increase in students' creativity.
Conclusion: The developed project-oriented biotechnology LKPD is valid (CVI = 0.895), practical (85.33%), and effective (N-Gain = 0.61) in enhancing students' creativity across all four dimensions fluency, flexibility, originality, and elaboration and supports the implementation of project-based learning in upper-secondary biology education.

INTRODUCTION

A preliminary study conducted prior to this research revealed that upper-secondary students demonstrated limited creative thinking abilities in biotechnology learning contexts. Observations and initial assessments showed that the majority of students scored below the expected creativity threshold, with an average pre-intervention creativity score of 37.60 out of 100. Students particularly struggled with generating original ideas (originality), producing diverse approaches to problems (fluency), and developing elaborated solutions. These findings indicated a clear need for instructional interventions that specifically target and cultivate students' creative capacities within biotechnology education.

Modern science education increasingly recognizes biotechnology as a critical domain that demands integration of theoretical knowledge, practical skills, and ethical reasoning (Harianto et al., 2026; Mims et al., 2024). However, secondary education systems continue to struggle with making biotechnology accessible and engaging for learners (Jiménez-Gaona & Vivanco-Galván, 2024). Students frequently encounter biotechnology concepts as abstract and disconnected from practical applications, which limits their ability to appreciate the field's relevance to contemporary society (Nurdin et al., 2025). Conventional teaching approaches that rely heavily on lecture-based instruction and textbook exercises have proven inadequate for developing higher-order cognitive skills and fostering innovative thinking (Rehman et al., 2024; Harianto et al., 2026). The contemporary educational landscape demands a shift toward pedagogies that prioritize exploration, critical inquiry, and authentic problem-solving aligned with 21st-century learning competencies (OECD, 2023). This imperative necessitates the development of instructional resources that transcend mere content delivery to actively cultivate students' creative capacities in biotechnology contexts.

Within science education, creativity represents a fundamental competency particularly vital for fields characterized by innovation, experimentation, and technological advancement (Rehman et al., 2024). For students at the upper-secondary level, creative thinking enhances scientific inquiry by enabling novel hypothesis generation, innovative solution design, and flexible problem-solving approaches (Pont-Niclòs et al., 2024). When students lack creative thinking skills, they tend to struggle with open-ended scientific tasks and demonstrate limited ability to generate novel solutions to complex biological problems (Sawyer & Henriksen, 2024). Research indicates that students deficient in creativity competencies are more likely to rely on rote memorization, exhibit lower engagement in inquiry-based tasks, and produce less sophisticated scientific reasoning—ultimately hindering their capacity to contribute meaningfully to science and technology fields (Rehman et al., 2024). Despite its importance, creativity does not emerge spontaneously but requires deliberately structured learning environments that promote divergent thinking, learner autonomy, and engagement with authentic challenges (Sawyer & Henriksen, 2024). Current classroom practices in biotechnology education often lack systematic opportunities for creative exploration, for instance the absence of hands-on practical activities, laboratory experiments, or open-ended project tasks (Widiyaningsih et al., 2024). Without intentional pedagogical scaffolding, students may fail to establish meaningful connections between scientific principles and innovative applications. This gap underscores the urgent need for creativity-centered instructional tools that guide learners through processes of observation, hypothesis formulation, experimentation, and critical reflection within biotechnology education.

The limitations described above particularly the absence of structured creativity-supporting materials highlight the need for a pedagogical approach that bridges theoretical content with authentic, hands-on scientific practice. Project-based learning (PjBL) has emerged as a robust pedagogical framework for enhancing creativity, inquiry skills, and conceptual depth across science disciplines (Zhang & Ma, 2023). By immersing students in authentic and purposeful projects, PjBL facilitates investigation of scientific problems, development of evidence-based solutions, and collaborative knowledge construction through hands-on engagement (Sukackė et al, 2022). These pedagogical principles align exceptionally well with biotechnology, a discipline fundamentally grounded in experimentation and real-world application (Mims et al., 2024). PjBL enables students to recognize biotechnology's presence in daily contexts including fermentation processes, tissue culture techniques, microbial applications, and genetic technologies. Empirical evidence consistently demonstrates PjBL's effectiveness in enhancing student motivation, critical thinking abilities, and creative performance (Kurt & Akoglu, 2023; Harianto et al., 2026). Nevertheless, successful implementation of PjBL requires carefully structured learning materials that provide systematic guidance through each project phase. The integration of PjBL principles into well-designed worksheets is therefore essential for creating coherent and creativity-supporting learning experiences in biotechnology education.

Learning worksheets (LKPD – Lembar Kerja Peserta Didik) function as pivotal instructional tools that shape student engagement, cognitive processes, and learning achievements (Septi et al, 2024). Effectively designed LKPD do more than organize learning sequences they prompt inquiry, stimulate critical analysis, and provide scaffolding for complex cognitive tasks (Azizah et al., 2022). In biotechnology contexts, LKPD can facilitate conceptual comprehension, laboratory investigations, and data interpretation through strategically sequenced activities and reflective prompts (Haatainen & Aksela, 2021). Unfortunately, existing worksheets frequently remain procedural, teacher-directed, and confined to basic instructions that rarely challenge students to engage in creative or independent thinking (Sumo et al., 2025). When students are exposed only to such conventional materials, they become passive recipients of information rather than active knowledge constructors, leading to reduced engagement, surface-level understanding, and underdeveloped creative thinking capacities (Rehman et al., 2024). These conventional materials typically isolate activities from genuine project-based principles, creating fragmented learning experiences that fail to sustain continuous inquiry. Such limitations highlight the necessity for LKPD that explicitly embed project components and creativity-focused tasks, ensuring students actively construct knowledge while engaging in meaningful biotechnology investigations.

Developing effective project-oriented biotechnology LKPD demands careful alignment with curricular standards, learner developmental stages, and the epistemic nature of scientific content (Larosa et al., 2024). What distinguishes the present LKPD from existing worksheets is its explicit integration of all four phases of PjBL orientation, planning, implementation, and evaluation directly within each biotechnology project activity, combined with built-in creativity assessment rubrics aligned to Torrance's indicators (fluency, flexibility, originality, and elaboration). Unlike conventional LKPD that present isolated lab instructions or factual exercises, this LKPD situates learning within authentic biotechnology contexts (e.g., fermentation, tissue culture, and microbial applications), requiring students to design experiments, analyze data, and propose innovative solutions. Quality LKPD must incorporate tasks that stimulate questioning, support experimentation, facilitate interpretation, and encourage innovation (Andriana et al, 2022).

Essential components include contextualized problem scenarios, structured project phases, inquiry-based prompts, data analysis activities, and reflective discussion opportunities. For biotechnology learning, this translates to guiding students through experimental design, variable identification, data collection and analysis, and development of application-oriented solutions (Haatainen & Aksela, 2021). Aligning these elements with the cognitive and creative developmental needs of upper-secondary students ensures LKPD promote both content mastery and creative competencies essential for meaningful engagement with biotechnology.

The implementation of project-oriented LKPD responds directly to contemporary educational priorities emphasizing active learning, scientific literacy, and 21st-century competencies (Setianingsih et al., 2025). Educational institutions increasingly acknowledge that students must develop creativity, collaboration, communication, and problem-solving capabilities to navigate complex scientific and technological landscapes (World Economic Forum, 2023). Biotechnology education offers exceptional opportunities to cultivate these competencies when supported by appropriate pedagogical resources (Deutscher et al., 2021). Project-based LKPD enable students to actively participate in experimental design, explore biological processes, and interpret data using authentic scientific methodologies. Such experiences strengthen their capacity to synthesize knowledge with creative thinking, preparing them to engage meaningfully with contemporary biotechnological challenges and innovations (Chappell et al., 2023).

Given these considerations, the development of project-oriented LKPD for biotechnology education represents a critical priority for enhancing instructional quality and fostering student creativity at the upper-secondary level. Systematically designed LKPD not only articulate clear learning objectives but also provide structured pathways for students to explore biotechnology through creative and inquiry-driven processes (Nag, 2023). By integrating authentic contexts, scientific reasoning, and creativity-oriented tasks, such LKPD can enhance student engagement, motivation, and innovative capabilities (Rahmayani & Indriyani, 2024). Furthermore, this development effort aligns with national curriculum objectives and supports teachers in implementing contemporary pedagogical practices. Therefore, this study focuses on the design, validation, and evaluation of project-oriented biotechnology LKPD aimed at enhancing student creativity across four dimensions: fluency, flexibility, originality, and elaboration. Beyond improving creativity scores, this research contributes to the broader goals of developing scientifically literate students equipped with 21st-century competencies, supporting teacher professional practice in implementing project-based learning, and advancing the quality of science education materials in the Indonesian upper-secondary context.

METHODS

This study employed a Research and Development (R&D) design to produce, validate, and test a project-oriented biotechnology worksheet (LKPD) intended to enhance students' creativity. The development process followed a structured sequence beginning with needs assessment, continued by product design, validation, practicality testing, and effectiveness evaluation. Each stage was implemented systematically to ensure that the resulting product met quality standards in terms of validity, practicality, and instructional effectiveness.

The research design followed a modified 4-D development model consisting of Define, Design, Develop, and Disseminate. This model was selected due to its clarity in guiding educational product development and its capacity to ensure that each stage undergoes systematic refinement (Thiagarajan et al., 1974). The Define stage included curriculum analysis, identification of student needs, and characterization of students' existing creative thinking abilities. The Design stage focused on preparing a prototype of the LKPD incorporating PjBL-aligned biotechnology project activities. The Develop stage involved expert validation, revision, and student practicality testing. The Disseminate stage involved broader implementation and evaluation of the product's usability and effectiveness.

The study involved upper-secondary students selected through purposive sampling to participate in the practicality and effectiveness trials. In addition, three experts were recruited to evaluate the validity of the LKPD: a biotechnology content expert, a pedagogical expert, and a learning media specialist. Their evaluations served as the foundation for improving the LKPD before student trials were conducted. The student participants represented diverse backgrounds to ensure that the practicality and effectiveness data reflected realistic conditions during classroom implementation.

Multiple instruments were used to ensure comprehensive data collection. Expert validation sheets were used to evaluate content accuracy, pedagogical suitability, media design, and alignment with creativity indicators. Student response questionnaires were administered to gather data on practicality and usability. A creativity test, structured around the Torrance Creative Thinking indicators fluency, flexibility, originality, and elaboration was used to measure learning effectiveness (Torrance, 1974; Kim, 2006). Additional instruments included observation sheets and documentation analysis to support qualitative interpretation of student engagement during the project activities. To determine the validity of the LKPD, expert judgments were analyzed using the Content Validity Index (CVI). The CVI was calculated at both item and scale levels to ensure rigorous assessment of each component. The formula used to calculate Item-Level CVI (I-CVI) is presented in Formula 1, which quantifies the proportion of experts who rated an item as relevant.

Formula 1. Item-Level CVI (I-CVI)

$$\text{I-CVI} = \frac{\text{Number of experts rating 3 or 4}}{N}$$

Once the I-CVI values were obtained, the average scale CVI (S-CVI/Ave) was computed to determine the overall validity of the LKPD, as shown in Formula 2.

Formula 2. Scale-Level CVI (S-CVI/Ave)

$$\text{S-CVI/Ave} = \frac{\sum \text{I-CVI}}{k}$$

The interpretation of CVI values follows the categories displayed in Table 1, which outlines the criteria for determining whether the LKPD is valid, very valid, or otherwise.

Table 1. Expert Validation Criteria

Score Range	Category
0.80–1.00	Very Valid
0.60–0.79	Valid
0.40–0.59	Less Valid
< 0.40	Invalid

(Polit & Beck, 2006)

Practicality was evaluated based on student responses to the LKPD after implementation. Students rated the clarity, usability, readability, and relevance of the LKPD. The percentage score for practicality was computed using Formula 3.

Formula 3. Practicality Percentage

$$P = \frac{\sum x}{\sum x_{\max}} \times 100\%$$

Table 2. Practicality Interpretation

Percentage (%)	Category
86–100	Very Practical
71–85	Practical
56–70	Fair
< 55	Not Practical

(Riduwan, 2013)

Effectiveness was measured through a one-group pretest–posttest design, focusing on students' creative thinking improvement after using the LKPD. To determine the magnitude of learning gains, the Normalized Gain Score (N-Gain) was used, as shown in Formula 4.

Formula 4. N-Gain

$$\textit{N-Gain} = \frac{(\textit{Posttest} - \textit{Pretest})}{(\textit{Maximum Score} - \textit{Pretest})}$$

Table 3. N-Gain Interpretation

N-Gain Score	Category
> 0.70	High
0.30–0.70	Medium
< 0.30	Low

(Hake, 1998)

Data analysis was performed using quantitative descriptive methods supported by qualitative interpretation. Validity results were analyzed by comparing CVI scores to the predetermined criteria. Practicality data were evaluated using percentage scores obtained from student questionnaires. Effectiveness was determined from N-Gain analysis per creativity dimension (fluency, flexibility, originality, and elaboration), supported by student product evaluations. The LKPD was declared feasible when it achieved CVI ≥ 0.80, practicality ≥ 71% (categorized as Practical or above), and N-Gain ≥ 0.30. Qualitative data from observations and student reflections were used to enrich interpretation and validate the quantitative findings.

RESULT AND DISCUSSION

The development of a project-oriented biotechnology worksheet (LKPD) using the 4D model generated several empirical findings related to expert validation, pedagogical design quality, student responses, and product effectiveness in enhancing creativity. Each stage of the 4D model Define, Design, Develop, and Disseminate produced specific outcomes that informed the final product.

In the Define stage, a curriculum analysis of the Merdeka Curriculum revealed that biotechnology learning objectives require students to engage in practical investigation and higher-order thinking. Needs analysis indicated that existing LKPD in use were predominantly procedural and lacked project-based or creativity-stimulating components. Student interviews and pre-test assessments confirmed that creative thinking abilities were below the expected threshold (mean

= 37.60/100). In the Design stage, an initial LKPD prototype was developed comprising five project activities aligned with upper-secondary biotechnology topics: (1) fermentation technology (yogurt and tempeh production), (2) tissue culture simulation, (3) microbial biocontrol applications, (4) bioremediation investigations, and (5) enzyme biotechnology. Each project was structured around the PjBL phases of orientation, planning, implementation, evaluation, and reflection, with embedded creativity-assessment rubrics. In the Develop stage, the prototype underwent validation by three experts, followed by revision and student practicality testing. In the Disseminate stage, the finalized LKPD was implemented with 30 upper-secondary students for effectiveness evaluation.

The biotechnology projects embedded in the LKPD were designed to provide authentic scientific contexts that connect curriculum content with real-world applications. For example, the fermentation project required students to design and conduct yogurt-making experiments, analyze fermentation variables, and propose product innovations thereby engaging fluency (generating diverse fermentation ideas), originality (designing novel flavor variants), and elaboration (documenting detailed process observations). The tissue culture project involved students in simulating aseptic technique procedures and investigating explant selection factors, fostering flexibility in scientific thinking. The bioremediation project engaged students in investigating the role of microorganisms in soil decontamination, connecting biotechnology to environmental sustainability. These projects collectively developed students' capacity for scientific inquiry, systems thinking, and creative problem-solving, while simultaneously deepening their understanding of biotechnology concepts and their societal implications. Expert validation was conducted to evaluate material feasibility, pedagogical alignment, and linguistic clarity. Following expert review, the LKPD was revised according to their recommendations before student trials were conducted. The detailed validation results and revisions are presented in Table 4.

Table 4. Expert Validation Results and Revision Summary

Validation Aspect	Score (%)	Category	Expert Recommendations & Revisions
Material Feasibility	91.2	Very Good	Add more explicit connections between biotechnology content and daily-life applications; expand discussion of project impact on society.
Pedagogical Alignment	89.7	Very Good	Clarify project phases instructions; add more scaffolding prompts for lower-ability students to support creativity development.
Language & Clarity	90.0	Very Good	Simplify some technical terms; add glossary for key biotechnology vocabulary to improve student comprehension.
Average	90.63	Very Good	All recommendations were incorporated in the revised LKPD prior to student trials.

Table 4 indicates that all evaluation aspects achieved scores above 89%, categorized as Very Good, demonstrating that the content quality, pedagogical structure, and linguistic clarity effectively support project-based learning and creativity development. These findings are consistent with established standards in educational research, which indicate that instructional materials scoring above 85% in expert validation are considered highly feasible for classroom implementation (Azizah et al., 2022; Fartina et al., 2024). The high validation scores reflect the LKPD's alignment with biotechnology curriculum standards and its capacity to facilitate student-centered learning approaches.

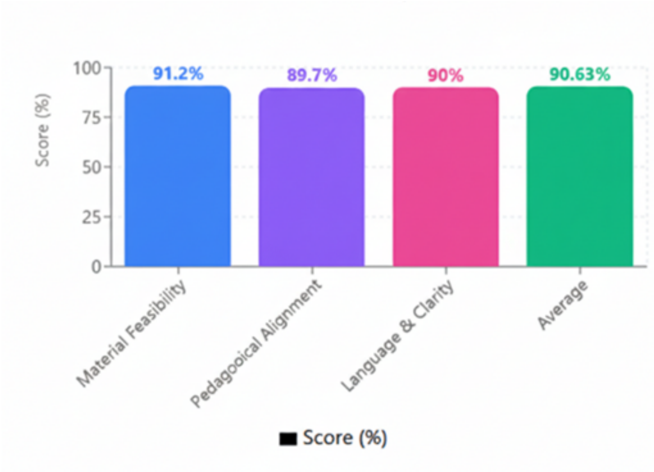

Figure 1. Expert Validation Results – Bar Diagram

The validation results demonstrated robust instructional design quality across all three dimensions, which is essential for ensuring effective implementation of project-based learning materials (Chung, 2022). The consistency among validation dimensions suggests that the LKPD successfully integrates content accuracy, pedagogical appropriateness, and communicative clarity three critical components for supporting meaningful biotechnology learning experiences.

During the development phase, several components of the project-oriented LKPD were refined based on expert recommendations. As summarized in Table 4 above, revisions addressed instructional clarity, activity structure, alignment with creativity indicators, and biotechnology content accuracy. Specifically, problem scenarios were made more contextually relevant, experimental protocols were restructured to better support student autonomy, creativity assessment rubrics were aligned more explicitly to Torrance's indicators, and visual presentation elements were enhanced for clarity and engagement.

These enhancements strengthened the LKPD's capacity to facilitate authentic scientific inquiry and creative problem-solving, which aligns with contemporary research emphasizing the importance of iterative design processes in developing high-quality educational materials (Larosa et al., 2024). The refinement process ensured that each project activity provided appropriate scaffolding while maintaining sufficient openness for creative exploration, thereby supporting both guided instruction and learner autonomy.

In addition to the practicality test (which yielded a score of 85.33%, categorized as Practical based on the structured practicality instrument), student response questionnaires were separately administered to measure usability, engagement, comprehensibility, and perceived effectiveness. While the practicality test assessed the functional suitability of the LKPD as an instructional tool, the student response questionnaire captured students' subjective perceptions and satisfaction across broader dimensions. The results are summarized in Table 5.

Table 5. Student Response Summary

Indicator	Score (%)	Category
Ease of Use	92.5	Very Good
Visual Attractiveness	94.1	Very Good
Content Understanding	90.8	Very Good
Motivation to Learn	93.4	Very Good
Average	92.70	Very Good

Table 5 demonstrates that students found the LKPD highly engaging and easy to navigate. High motivation scores (93.4%) suggest that project-based activities effectively stimulated learning interest and sustained engagement throughout the biotechnology learning process. This result is consistent with empirical evidence demonstrating that well-designed interactive learning materials significantly enhance students' intrinsic motivation and active participation (Suharsono & Handayani, 2022). The positive student perceptions across all measured dimensions indicate that the LKPD successfully balanced instructional guidance with opportunities for independent exploration and creative expression.

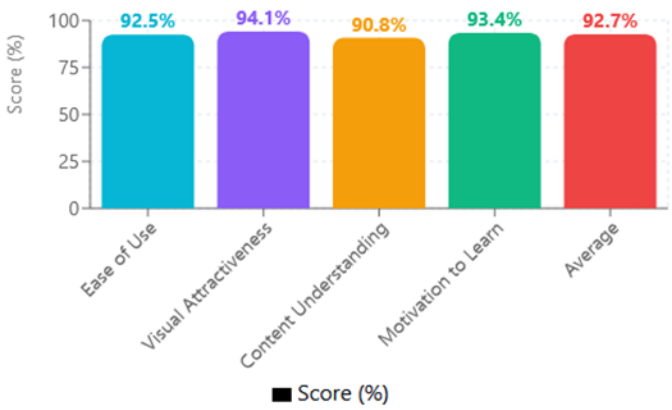

Figure 2. Student Response Diagram

Figure 2 confirms that visual attractiveness scored highest (94.1%), indicating that the interface design, layout organization, and graphic elements played a significant role in capturing and maintaining student engagement. Research has consistently shown that visually appealing instructional materials positively affect learning concentration, comprehension, and overall satisfaction (Tomita, 2022). The strong visual appeal of the LKPD likely contributed to students' willingness to engage deeply with the project activities and persist through challenging problem-solving tasks. Empirical data from classroom implementation revealed that students demonstrated substantial improvements in creative thinking abilities across all four dimensions of the Torrance Test of Creative Thinking. The N-Gain values per dimension are presented in Table 6.

Table 6. N-Gain Results per Creativity Dimension

Creativity Dimension	Pretest Mean	Posttest Mean	N-Gain	Category
Fluency	38.20	77.50	0.72	High
Flexibility	36.80	73.40	0.58	Medium
Originality	35.40	78.10	0.76	High
Elaboration	40.00	74.50	0.58	Medium
Overall	37.60	75.87	0.61	Medium

Table 6 shows that particularly notable gains were observed in originality (N-Gain = 0.76, High) and fluency (N-Gain = 0.72, High), while flexibility and elaboration achieved moderate gains (N-Gain = 0.58 each). The overall N-Gain of 0.61 falls in the Medium category, with the Wilcoxon Signed Ranks Test confirming statistical significance ($p = 0.000 < 0.05$). These results demonstrate that the project-based biotechnology LKPD was most effective in stimulating students' ability to generate diverse ideas and produce original solutions, which are core indicators of scientific creativity (Sawyer & Henriksen, 2024).

The differential gains across creativity dimensions can be attributed to the nature of each construct and the instructional design of the LKPD. Originality and fluency are more readily stimulated through short-term project activities that encourage idea generation and novel solution design, as these dimensions require students to produce diverse and unique responses within defined contexts. In contrast, flexibility and elaboration demand higher-order cognitive restructuring and sustained refinement of ideas across multiple stages, which require extended practice and more complex scaffolding beyond a single instructional cycle. This pattern is consistent with prior research suggesting that flexibility and elaboration develop more gradually and benefit from repeated exposure to open-ended, reflective tasks (Sawyer & Henriksen, 2024). The key advantage of this LKPD lies in its explicit integration of all four PjBL phases within each biotechnology project, combined with built-in creativity rubrics aligned to Torrance's indicators, which provide students with structured yet open-ended opportunities to develop all dimensions of creative thinking. To further enhance flexibility and elaboration, future improvements should incorporate more open-ended reflection prompts, extended project timelines, and differentiated scaffolding tasks tailored to varying student ability levels.

These improvements align with previous findings demonstrating that project-based learning environments significantly enhance creative cognition and scientific reasoning capabilities (Rehman et al., 2024; Harianto et al., 2026). Harianto et al. (2026) similarly demonstrated that ethno-STEM-based instructional materials integrating authentic local contexts with scientific inquiry effectively enhanced students' higher-order thinking and conceptual understanding a finding that corroborates the present study's approach of situating biotechnology learning within real-world project contexts. The structured project activities embedded in the LKPD provided students with authentic opportunities to engage in hypothesis generation, experimental design, data interpretation, and solution development processes that are fundamental to both scientific inquiry and creative thinking. Furthermore, the integration of reflection prompts and peer feedback mechanisms helped students metacognitively monitor their thinking processes, supporting deeper conceptual understanding and more sophisticated creative outputs (Rehman et al., 2024). The effectiveness of the LKPD in fostering creativity demonstrates that carefully designed project-based materials can successfully cultivate higher-order cognitive skills essential for meaningful engagement with biotechnology and broader scientific domains.

CONCLUSION

The development of a project-oriented biotechnology worksheet (LKPD) using the 4D model (Define, Design, Develop, and Disseminate) resulted in a highly valid, practical, and effective instructional product for enhancing students' creativity in biotechnology learning. Expert validation data confirmed that the LKPD met Very Good standards in terms of material accuracy (91.2%), pedagogical alignment (89.7%), and linguistic clarity (90.0%), with an overall CVI of 0.895, demonstrating strong feasibility for classroom use. Student responses further indicated exceptionally positive perceptions regarding usability (92.5%), visual design (94.1%), content comprehension (90.8%), and learning motivation (93.4%), with an overall score of 92.70%. The effectiveness test revealed significant creativity improvement across all four dimensions: fluency (N-Gain = 0.72, High), flexibility (N-Gain = 0.58, Medium), originality (N-Gain = 0.76, High), and elaboration (N-Gain = 0.58, Medium), with an overall N-Gain of 0.61 (moderate category). The Wilcoxon Signed Ranks Test confirmed statistical significance ($p = 0.000 < 0.05$). The integration of project-based activities, creativity-focused tasks, and authentic biotechnology experiments proved effective in strengthening students' creative thinking abilities across all dimensions. The consistent findings across expert validation, development refinements, and student responses confirm that the project-oriented LKPD is well-designed to support creativity development in biotechnology learning contexts. Overall, the results demonstrate that the developed LKPD is not only valid and practical but also pedagogically powerful in fostering creativity, deeper conceptual understanding, and meaningful engagement with biotechnology. The key advantages of this LKPD lie in its explicit integration of all four PjBL phases within each biotechnology project activity, its built-in creativity assessment rubrics aligned to Torrance's indicators, and its contextual grounding in authentic biotechnology applications such as fermentation, tissue culture, and bioremediation.

These features collectively make the LKPD more structured and creativity-conducive than conventional worksheets. However, several limitations should be acknowledged. The moderate N-Gain scores in flexibility (0.58) and elaboration (0.58) suggest that students may require more guided scaffolding and extended project timelines to fully develop these dimensions. Future improvements to the LKPD should include more open-ended reflection prompts, expanded peer-assessment rubrics, and differentiated tasks to address varying student ability levels. Additionally, broader dissemination involving larger and more diverse student populations across different school settings is recommended to further validate the LKPD's effectiveness and generalizability in upper-secondary biology education.

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