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DEVELOPMENT OF LOCAL MEDICINAL PLANT BIOTECHNOLOGY PRODUCTS THROUGH PROJECT-BASED LEARNING TO ENHANCE BIOTECHNOLOGY LITERACY, CREATIVITY AND SCIENCE PROCESS SKILLS

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ABSTRACT

Biotechnology learning in higher education often faces challenges in connecting theoretical concepts with practical applications and the development of essential 21st-century skills. This study aims to describe the development of biotechnology products based on local medicinal plants through the Project-Based Learning (PjBL) model and to analyze its potential in improving biotechnology literacy, creativity, and science process skills among Biology Education students. This research employed a Research and Development (R&D) approach using the ADDIE model and involved undergraduate students in the Biology Education program. The results indicated that the implementation of PjBL through projects exploring local medicinal plants, such as tissue culture explants, bioprospecting of nut grass tubers (Cyperus rotundus), and the utilization of local wisdom through edible fern (Diplazium esculentum), was highly effective. This learning approach significantly improved students' cognitive learning outcomes (p-value = 0.009), science process skills, and creativity. Project success was demonstrated by high practical achievement rates, including 100% in preparing sterile culture media and 89% in obtaining sterile explants for tissue culture. Therefore, local medicinal plant-based PjBL represents an innovative and effective approach for preparing prospective biology educators who are competent, creative, and equipped with an appreciation of local wisdom.

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INTRODUCTION

The advancement of science and technology in the 21st century demands that university graduates possess critical thinking, creativity, collaboration, and communication skills as core competencies to face global challenges (Partnership for 21st Century Skills, 2019). Higher education is currently no longer oriented solely toward knowledge mastery but also toward students' ability to apply knowledge to solve various real-world problems (OECD, 2023). Therefore, the learning process needs to be designed contextually and student-centered to develop competencies relevant to 21st-century needs (UNESCO, 2021).

Biotechnology is one of the rapidly developing scientific fields that makes significant contributions to health, food, environment, and industry (Bybee, 2018). Biotechnology learning in higher education is expected to equip students with conceptual understanding as well as applicative skills relevant to modern technological developments (Akyol et al., 2022). However, biotechnology learning is still often dominated by theoretical approaches, causing students to experience difficulties in connecting concepts with their applications in everyday life (Sudarisman, 2015).

One of competency that needs to be developed in biotechnology learning is biotechnology literacy. Biotechnology literacy not only encompasses conceptual mastery but also the ability to understand processes, evaluate scientific information, and make appropriate decisions regarding biotechnology applications in daily life (Holbrook & Rannikmäe, 2009). Biotechnology literacy is the ability to understand concepts, processes, benefits, risks, and implications of biotechnology applications in society (Çimer, 2012). Biotechnology literacy also includes the ability to evaluate scientific information and make decisions based on available evidence (Holbrook & Rannikmäe, 2009). Good mastery of biotechnology literacy is necessary for students to critically and responsibly respond to biotechnology issues (Fauville et al., 2018).

Creativity is one of the essential competencies that students must possess in the 21st century (Henriksen et al., 2020). Creativity enables students to generate new ideas, modify existing concepts, and develop innovative solutions to problems (Runco & Acar, 2012). Learning environments that provide opportunities for students to design and produce tangible products have been proven to significantly enhance creativity (Beghetto, 2019).

Science process skills are a set of skills used to acquire, develop, and communicate scientific knowledge (Padilla, 1990). These skills include the ability to observe, classify, measure, predict, interpret data, and draw conclusions (Rustaman, 2005). Good mastery of science process skills will help students understand the nature of science and conduct research systematically (Aktamis & Ergin, 2008).

One learning model that has the potential to address these issues is Project-Based Learning (PjBL). Project-Based Learning is a learning approach that facilitates students to pose questions, conduct investigations, and produce products through a structured research process (Bell, 2010). This model provides opportunities for students to design solutions to problems, integrate various concepts learned, and present project outcomes (Thomas, 2000). The implementation of PjBL has been proven to enhance students' higher-order thinking skills, creativity, and scientific skills (Krajcik & Blumenfeld, 2006). Furthermore, project-based learning provides opportunities for students to analyze information, evaluate evidence, and make data-based decisions, thereby improving critical thinking skills in solving real-world problems (Lubis & Sapitri, 2025).

On the other hand, Indonesia possesses enormous biodiversity, including various types of medicinal plants with potential for development into biotechnology products. Local medicinal plants can be utilized as raw materials in tissue culture development, fermentation products, biofertilizers, bioactivators, and exploration of bioactive compounds beneficial for health and the environment (Suastra, 2017). However, this potential has not been optimally utilized as a learning resource in Biotechnology courses

(Rote, 2015). Learning generally still uses general examples of biotechnology products and rarely highlights local biological wealth close to students' lives (Jufri, 2018). Consequently, students lack awareness of local medicinal plants' potential as a source of biotechnology innovation that can be developed through scientific activities and science-based entrepreneurship.

The utilization of local potential in learning can enhance the relevance of materials to students' lives (Rote, 2015). Indonesia has a highly potential diversity of medicinal plants that can serve as learning resources in biotechnology education (Suastra, 2017). Integrating local medicinal plants into learning also contributes to preserving local wisdom and developing innovations based on regional resources (Jufri, 2018).

Based on the aforementioned explanation, there is a need for learning innovations that can integrate biotechnology concepts with local potential through project-based activities (Thomas, 2000). The development of local medicinal plant biotechnology products through Project-Based Learning has the potential to enhance students' biotechnology literacy through authentic learning experiences (Holbrook & Rannikmäe, 2009). Additionally, this approach is expected to optimize the improvement of creativity and science process skills among Biology Education students (Bell, 2010).

RESEARCH METHOD

This study employed the Research and Development (R&D) method by adapting the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The ADDIE model was chosen because it provides systematic and comprehensive stages for developing learning products that meet valid, practical, and effective criteria. The product developed consisted of Project-Based Learning (PjBL)-based learning tools and activities oriented toward developing biotechnology products based on local medicinal plants to enhance biotechnology literacy, creativity, and science process skills among Biology Education students.

Analysis

The analysis stage was conducted to identify learning needs in the Biotechnology course within the Biology Education Study Program. The analysis included curriculum review, course learning outcomes, student characteristics, and 21st-century competency development needs. Additionally, identification of local medicinal plant potential that could be utilized as learning resources and objects for biotechnology product development was conducted, including plants with potential for tissue culture, bioactive compound bioprospecting, fermentation products, and other biotechnology applications. The analysis results served as the basis for designing contextual and relevant project-based learning activities aligned with the students' environment.

Design

At the design stage, learning tools were developed, including Semester Learning Plans (RPS), Unit Lesson Plans (SAP), and Student Worksheets (LKM) based on Project-Based Learning. Furthermore, research instruments were designed to measure product effectiveness, including biotechnology literacy tests, science process skills tests, creativity observation sheets, learning implementation observation sheets, and student response questionnaires. All instruments were designed based on predetermined indicators and tailored to the research objectives.

Development

The development stage involved compiling modules or textbooks that integrate biotechnology concepts with product development projects based on local medicinal plants. The developed materials contained basic biotechnology concepts, practical procedures, project implementation guidelines, and investigative activities that encouraged students to explore the potential of local medicinal plants. The developed products were subsequently validated by material experts, instructional media experts, and educational practitioners to obtain feedback on content, presentation, language, and learning feasibility

aspects. Validation results were used as the basis for revision and product refinement before implementation.

Implementation

Product implementation was conducted through trials with Biology Education Study Program students. The research employed a pretest-posttest control group design, involving both experimental and control classes. The experimental class followed learning using the Project-Based Learning model based on local medicinal plant biotechnology product development, while the control class followed learning using the method commonly employed by the lecturer.

Learning implementation in the experimental class followed the Project-Based Learning syntax consisting of: (1) presenting fundamental questions regarding the utilization of local medicinal plants as biotechnology products, (2) project design by students, (3) project activity schedule preparation, (4) project execution and monitoring, (5) product testing and analysis of developed outcomes, and (6) presentation and reflection on the learning experience. During the implementation process, students worked collaboratively to develop biotechnology products based on local medicinal plants according to the project design that had been prepared.

Evaluation

The evaluation stage was conducted both formatively and summatively. Formative evaluation was carried out at each development stage to obtain feedback used for product refinement. Meanwhile, summative evaluation was conducted to determine the effectiveness of the developed learning products. Product effectiveness was analyzed based on improvements in biotechnology literacy, creativity, and science process skills among students through comparison of pretest and posttest scores in both experimental and control classes. The obtained data were analyzed using descriptive and inferential statistics, such as normality tests, homogeneity tests, independent sample t-tests, or Multivariate Analysis of Variance (MANOVA) according to the characteristics of the research data.

RESULT AND DISCUSSION

Improvement in Biotechnology Literacy and Student Learning Outcomes

The research results showed that the implementation of Project-Based Learning (PjBL) based on local medicinal plants had a positive impact on improving biotechnology literacy and learning outcomes among Biology Education students. This improvement was evident in students' ability to understand biotechnology concepts, connect theory with real applications, and evaluate the utilization of local biological resources as materials for biotechnology product development.

Learning outcome data showed a significant increase between students' pretest and posttest scores. In project-based learning that integrated medicinal plant tissue culture activities, the average student score increased from 37.40 on the pretest to 83.90 on the posttest. These results indicate that student involvement in project activities was able to strengthen conceptual understanding through authentic and contextual learning experiences.

These findings align with research reporting that the use of teaching materials based on local wisdom and laboratory experiment activities in biotechnology courses significantly improved students' cognitive learning outcomes (p-value = 0.009). The improvement in biotechnology literacy occurred because students not only studied concepts theoretically but also applied these concepts in exploration, identification, and product development activities based on local medicinal plants. Through this process, students gained a deeper understanding of the principles, benefits, and potential applications of biotechnology in everyday life.

Improvement in Science Process Skills

Science process skills are one of the core competencies developed in project-based biotechnology learning. These skills include the ability to observe, classify, measure, predict, design experiments, interpret data, communicate results, and draw scientific conclusions. The implementation of PjBL provided opportunities for students to be directly involved in all stages of the scientific method, allowing science process skills to develop optimally.

The research results showed that students experienced improved abilities in conducting scientific investigations during project implementation. These findings align with research applying the STEM-PjBL approach, which demonstrated that integrating project activities with scientific processes significantly improved students' science process skills and learning outcomes. Other research on local potential-based fermentation biotechnology learning also showed that PjBL positively influenced students' evaluation and reflection abilities as part of science process skills.

The improvement in science process skills was evident from students' success in implementing local medicinal plant biotechnology projects. In tissue culture activities, students demonstrated good laboratory skills with a 100% success rate in sterile media preparation, while explant sterilization and growth success reached 89%. These achievements indicate that students were able to apply scientific procedures accurately, control research variables, conduct systematic observations, and interpret experimental results accurately.

Thus, local medicinal plant-based PjBL not only improved conceptual mastery but also provided authentic scientific experiences, enabling students to develop science process skills necessary for future research activities and biology instruction.

Development of Student Creativity and Innovation

Creativity is one of the essential 21st-century skills in developing biotechnology innovations. In this study, student creativity developed through exploration activities of local medicinal plants, project design, problem-solving, and the development of biotechnology products with practical value for society.

The implementation of PjBL provided space for students to generate new ideas based on available local resource potential. Students were not only required to understand the characteristics of local medicinal plants but also to design various alternative uses in the form of innovative biotechnology products. These activities encouraged students to think divergently, explore various possible solutions, and develop products with scientific and economic value.

The results of this study are supported by various studies showing that PjBL significantly affects the improvement of students' creative thinking abilities. Research on multimedia-based biotechnology learning reported a significant improvement in creativity with $p = 0.000$. Other findings show that integrating the STEM-PjBL approach in medicinal plant bioprospecting activities encourages the emergence of creativity alongside entrepreneurial spirit among students because they are directly involved in the identification, development, and evaluation processes. For example, several medicinal plant bioprospecting studies have successfully produced innovative products with potential for further development at an industrial scale. This indicates that project-based learning can serve as a bridge between academic activities in higher education and the downstream process of research outcomes. Therefore, the development of biotechnology products based on local medicinal plants through PjBL has great potential to produce graduates who are creative, innovative, and adaptive to community needs.

Contextualization of Learning through Local Potential

One of the main advantages of the project-based learning developed in this study is its ability to integrate local potential into the learning process. The utilization of local medicinal plants as project objects made learning closer to students' lives, making

biotechnology concepts more relevant and meaningful.

Indonesia possesses very high biodiversity with various types of medicinal plants that have potential for development into biotechnology products. However, this potential has not been widely utilized as a learning resource in biotechnology education. Through the PjBL approach, students were given the opportunity to directly explore the potential of local medicinal plants found in their surrounding environment, enabling them to understand the relationship between science, technology, and local wisdom.

Previous research has shown that the development of biotechnology teaching materials based on local wisdom proved to be valid, practical, and effective in improving student learning outcomes. In addition to enhancing conceptual understanding, this approach also fostered a sense of pride in local biological wealth and increased students' awareness of the importance of conserving Indonesia's natural resources. Thus, the integration of local medicinal plants in biotechnology learning not only serves as a learning resource but also as a means to build character, cultural identity, and concern for environmental sustainability. Overall, the research results show that the development of local medicinal plant biotechnology products through Project-Based Learning is capable of simultaneously improving biotechnology literacy, creativity, and science process skills among students. This approach provides authentic, contextual, and competency-oriented learning experiences for 21st-century skill development, making it worthy of implementation as a learning innovation in the Biotechnology course within the Biology Education Study Program.

Table 1. Development Stage Activity and Supporting Evidence

Sequence	Activity	Results/Data from Article
1	Module & instrument production	Biotechnology Module based on PjBL & Local Wisdom was created.
2	Material & Media Expert Validation	Material validation score reached **91.68%** (Very Feasible category).
3	Product Revision	Improvements based on expert suggestions enhanced content quality and design.
4	Practicality Trial	Initial student responses were positive (e.g., STEM-PjBL module for nut grass was considered beneficial for enhancing entrepreneurial insight).
5	Device Finalization	Product ready for Implementation in the experimental class.

By following this sequence, the Development stage ensures that the resulting product is not only conceptually innovative but also valid, practical, and effective before being used to measure improvements in literacy, creativity, and science process skills among students.

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