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# Development of Project-Based Learning Assisted by Modules and the Ethnopedagogy of "Tapai Making" in Biotechnology Materials to Enhance Learning Motivation and Creativity of Phase E Students

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A B S T R A C T
Biotechnology content at Phase E is often perceived as abstract, so students' learning motivation and creativity are not yet optimal.. Research and development used the ADDIE model. Feasibility was assessed by a content expert, a media expert, and two practitioners, and readability was tested with six students. Motivation and creativity instruments underwent content validation and empirical validity testing with 24 students, and all items met the criteria. MANOVA prerequisite tests included normality, Box's Test, and Levene. The supporting lesson plan (RPP) was also validated (mean 3.79, high category), and the tapai project was designed through planning, experimentation, documentation, presentation, and reflection stages. Effectiveness was tested using a pretest–posttest control group design in two Grade X classes at SMAN 1 Kampar Timur (30 students in each class) with N-gain and MANOVA analyses. Content expert validation was in the high category (mean 3.45), media expert validation was in the moderate category (2.60), and practitioner validation was high (3.61 and 3.95). Readability testing indicated a very high category (scores 92–99). The PjBL e-module with the tapai ethnopedagogical approach is feasible for use and effectively improves Phase E students' motivation and creativity in biotechnology content, and it has the potential to be adopted in other schools.

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## INTRODUCTION

Biotechnology learning at Phase E requires students not merely to memorize concepts, but to reason about processes, make evidence-based decisions, and generate ideas that are relevant to everyday life. Meta-analytic evidence indicates that Project-Based Learning (PjBL) tends to have a positive impact on science learning outcomes across educational levels (Nurhasnah et al., 2022). However, biology classes often face motivational problems when biotechnology content is perceived as abstract and distant from students' cultural experiences, leading to reduced learning engagement. This impact is reflected in low participation, curiosity, and persistence. Integrating local wisdom into science learning has been reported to improve conceptual connectedness and scientific literacy through meaningful contexts (Verawati & Wahyudi, 2024). In addition, systematic reviews emphasize the need for interactive learning resources such as e-modules to support visualization of complex biological concepts (Herlinawati & Suhartini, 2025). Therefore, biotechnology innovation needs to be designed contextually, grounded in authentic activities, and supported by learning materials that guide students' thinking processes so that motivation and creativity develop sustainably.

PjBL is relevant for biotechnology because it provides room for exploring real problems, collaboration, and products that can be tested, so students experience autonomy and meaningful learning. Action research in secondary schools shows that teachers often face dilemmas in maintaining students' motivation during PjBL, especially during the planning phase, role distribution, and assessment (Nicolás & Ramos-Ramos, 2022). These conditions require adaptive scaffolding, particularly for students with varying learning readiness. The effectiveness of PjBL is also influenced by how learning is arranged into authentic tasks, clear rubrics, and learning resources that enable students to complete projects systematically. Evidence from classroom studies indicates that the PjBL approach can increase motivation when students are involved in active processes and feel responsible for outcomes (Pramesti et al., 2022). In addition, studies show that PjBL can strengthen motivation and creative thinking when projects are relevant and supported by structured learning tools (Akbar et al., 2025). Therefore, development of PjBL-based biotechnology learning requires explicit pedagogical support so that students remain motivated, can innovate, and can complete projects to completion.

The success of PjBL in biotechnology is influenced by the quality of learning materials that guide investigation, work procedures, and reflection on outcomes. Module-based learning materials allow the project structure to be presented in stages, from problem orientation, experiment planning, data processing, to product communication, so students' cognitive load is more manageable. Evaluation of interactive digital books indicates that interactive features can strengthen learning motivation as well as conceptual understanding when presented systematically (Susanti et al., 2022). Digital modules also support independent learning because students can access materials, project steps, and evaluation criteria flexibly. This aligns with the results of systematic reviews showing that e-modules can be effective when they incorporate learning

activities, evaluation, and guidance that facilitates engagement and independent practice (Sobach et al., 2023). In addition, e-module development in schools is recommended to be guided by classroom needs analysis to ensure relevance to students' characteristics and context (Saragih & Tanjung, 2023). Thus, the development of a biotechnology e-module should function not only as content delivery, but also as a project roadmap that is multimodal and facilitates reflection, so that motivation and creativity grow through a guided process.

Tapai is a traditional fermented product that is rich in cultural meaning and also loaded with biotechnology concepts, ranging from selecting ingredients and yeast inoculum to chemical changes during the process. A study on Sundanese fermented foods emphasized that local fermentation practices contain empirical knowledge about microbes and process parameters, so they have the potential to serve as a bridge for culture-based science learning (Cempaka, 2021). Microbiology studies on glutinous rice tapai also describe bacterial community structures and product characteristics, indicating that tapai fermentation can be studied scientifically and linked to biotechnology concepts at the school level (Barus et al., 2023). Local fermented foods can serve as authentic contexts for projects that train students to design procedures, identify variables, document processes, and communicate outcomes. The use of fermentation topics in learning is also relevant to PjBL because it allows products to be produced and evaluated. Such projects can be expected to develop students' creative thinking through idea generation, procedure modification, and product improvement, consistent with project learning oriented to creativity development (Prasetyo & Rasmiyana, 2025). Thus, tapai is a viable ethnopedagogical context for biotechnology projects that integrate scientific investigation with cultural practices.

The use of local wisdom in science learning is increasingly receiving attention, but its implementation still requires operational instructional tools that are easy to replicate. Bibliometric analysis shows an increase in publications on local wisdom in science learning and also marks the need for consistent implementation models at the classroom level (Setianingrum et al., 2023). In secondary schools, local-wisdom-based STEM learning has been reported to improve environmental literacy because students engage in contextual problem solving and projects (Yolida et al., 2025). However, implementing ethnoscience-based learning often requires teacher competencies in designing learning materials and digital modules that align with local contexts and competency targets. Studies on biology teacher candidates show that the ability to develop electronic modules based on STEM and ethnoscience is important to support contextual learning and skills development (Alisah et al., 2025). Therefore, developing an e-module that integrates PjBL with ethnopedagogy requires clear instructional procedures, assessment rubrics, and contextual learning resources so that students can learn independently as well as collaboratively.

Although many studies support PjBL, recent evidence indicates that its impact on creativity is influenced by the quality of project design and the support provided by learning materials (Kwon & Lee, 2025). Instructional development requires an instructional design framework so that objectives, activities, and

evaluation are aligned in STEM education in schools (Halawa et al., 2024). Development research emphasizes systematic design and feasibility testing to ensure products are effective and easy for teachers to use (Kwangmuang et al., 2021). In this context, developing a biotechnology e-module that integrates the ethnopedagogy of "tapai making" is expected to produce a learning tool that is feasible and effective for improving motivation and creativity among Phase E students, while providing an example of integrating local culture into a science project that can be adapted by other schools.

## RESEARCH METHODOLOGY

### Research Type and Design

This study employed research and development (R&D) to produce a science e-module based on Project Based Learning (PjBL) and ethnopedagogy, accompanied by a lesson plan (RPP). The developed product was then tested using a pre-test–post-test control group experimental design, so measurements were conducted before and after treatment in the experimental and control groups.

**Table 1. Pre-test–Post-test Control Group Design (summary of Table 3.2)**

| Class | Pre-test | Treatment | Post-test |
|---|---|---|---|
| Experimental | O1 | X2 | O2 |
| Control | O3 | X1 | O4 |

### Product Development Model and Procedure (ADDIE)

The e-module development adapted the ADDIE model (Analyze, Design, Development, Implementation, and Evaluation). The development procedure included needs analysis, product design, development and validation, implementation through field trials, and continuous evaluation and revision.

**Table 2. Product Development Procedure (ADDIE) (summary of Table 3.1)**

| Stage | Main Activities |
|---|---|
| Analysis | Field study, needs analysis, interviews, questionnaire distribution, and data analysis |
| Design | Determining the initial product design, preparing an outline, and designing the e-module layout and lesson plan (RPP) |
| Development | Developing the e-module, expert validation, revision, limited trial, and further revision |
| Implementation | Field trial in experimental and control classes (pre-test, learning activities, and post-test) |
| Evaluation | Evaluation of product quality and effectiveness and improvements based on feedback and trial results |

### Location and Trial Subjects

Development and implementation were conducted at SMA Negeri 1 Kampar Timur. During the needs analysis stage, observations and interviews were conducted with biology teachers, accompanied by a needs analysis questionnaire distributed to students via Google Form to map learning needs and media or module needs.

The trial subjects consisted of:

- A limited trial (readability) with six Phase E students with high, moderate, and low ability classifications (two students per category), determined based on learning outcomes.
- A field trial involving two classes (control and experimental) from four biology classes, with class selection through group randomization (lottery). The control class was group 3 and the experimental class was group 2.

**Developed Product**

The main product was an e-module compiled for Phase E learning outcomes and used together with an RPP. The e-module structure included a cover, preface, concept map, user guide, learning outcomes, learning objectives, learning activities, evaluation, glossary, references, and author biography. In the learning activities section, the e-module included content, PjBL syntax, supporting text, images, and videos, and reinforcement of the context (ethnopedagogy) connected to learning.

**Data Collection Techniques and Instruments**

Data collection used non-test and test techniques. Non-test techniques included interviews and questionnaires, and the test technique measured achievement before and after treatment.

***Interview (Needs Analysis)***

Interviews were used to identify learning problems related to content, media, motivation, and creativity as the basis for product development. The interview blueprint is summarized below.

**Table 3. Interview Blueprint (Table 3.3)**

| No. | Aspect | Indicator | Item numbers | Number of items |
|---|---|---|---|---|
| 1 | Learning materials | Materials used | 1–4 | 4 |
| 2 | Learning model | Model used | 5–8 | 4 |
| 3 | Learning motivation | Student motivation | 9–11 | 3 |
| 4 | Student creativity | Student creativity | 12–13 | 2 |

***Expert and Practitioner Validation***

Validation instruments were used to assess e-module feasibility by a content expert, a media expert, and practitioners. The validation blueprint by media experts and practitioners included indicators such as cover and content, objectives, materials, examples and practice activities, references, layout, and language.

***Student Response Questionnaire for Product Feasibility***

A response questionnaire was administered after revisions based on validation results to measure ease of use, presentation, and product benefits as perceived by students, using a 1–5 scale. The blueprint is presented below.

**Table 4. Student Response Questionnaire Blueprint for Product Feasibility (Table 3.6)**

| Aspect | Indicator | Item numbers | Number of items |
|---|---|---|---|
| Interest | E-module appearance | 1–5 | 8 |
| Interest | Operation and user instructions | 6–8 | |
| Materials | Material design | 9–12 | 17 |
| Materials | Presentation of material content | 13–16 | |
| Materials | Language use | 17–18 | |
| Materials | Integration of everyday-life problems | 19–21 | |
| Materials | Interactive questions and assignments | 22–23 | |
| Materials | Practice questions | 24–25 | |
| | Total items | | 25 |

***Student Creativity Assessment Questionnaire***

Creativity was assessed using a questionnaire with fluency, flexibility, originality, and elaboration dimensions. The creativity blueprint was formulated in 20 items.

**Table 5. Student Creativity Assessment Blueprint (Table 3.7, summary)**

| Aspect | Indicator | Item numbers | Total |
|---|---|---|---|
| Fluency | Generating creative information in biotechnology practicum and generating ideas or answers | 1–6 | 6 |
| Flexibility | Solving problems from different viewpoints and seeking practical methods | 7–12 | 6 |
| Originality | Creating solutions in assigned tasks | 13–14 | 2 |
| Elaboration | Identifying the basis of a problem and elaborating ideas or tasks | 15–20 | 6 |

**Data Analysis Techniques**

***Preliminary Study Analysis***

Initial data from interviews and the needs analysis questionnaire were analyzed to establish learning needs and the need for e-module development.

***Product Feasibility Analysis***

Assessment data from experts, practitioners, teachers, and students were converted from qualitative to quantitative form using 1–5 scores. The score conversion criteria and interpretation of feasibility percentages referred to the following tables.

**Table 6. Conversion of Qualitative Data to Quantitative Scores (Table 3.8)**

| Appropriateness category | Score |
|---|---|
| Very appropriate | 5 |
| Appropriate | 4 |
| Moderately appropriate | 3 |
| Inappropriate | 2 |
| Very inappropriate | 1 |

**Table 7. Product Feasibility Criteria (Table 3.9)**

| Percentage (%) | Criteria |
|---|---|
| $0 \leq X \leq 25$ | Very infeasible |
| $25 < X \leq 41$ | Infeasible |
| $41 < X \leq 50$ | Moderately feasible |
| $50 < X \leq 75$ | Feasible |
| $75 < X \leq 100$ | Very feasible |

A PjBL-based e-module is considered theoretically feasible when the feasibility percentage is at least 45.5%.

***Creativity Analysis***

Creativity scores were calculated as percentages and categorized based on creativity mastery levels.

**Table 8. Creativity Mastery Level Categories (Table 3.10)**

| Percentage | Category |
|---|---|
| 86–100% | Very good |
| 76–85% | Good |
| 60–75% | Moderate |
| 55–59% | Low |
| 54% | Very low |

***Analysis of Motivation Improvement (Pre-test–Post-test and N-gain)***

Motivation improvement was measured through pre-tests and post-tests in the experimental and control classes. Each correct answer was scored 5, and improvement was calculated using N-gain and categorized.

**Table 9.** Interpretation Categories for N-gain (Table 3.11)

| N-gain value | Interpretation |
|---|---|
| $g > 0.7$ | High |
| $0.3 \leq g \leq 0.7$ | Moderate |
| $g < 0.3$ | Very low |

In addition, statistical test selection was described as being adjusted to the number of subjects. When the number of subjects is greater than 30, a t-test can be used, whereas when it is fewer than 30, Wilcoxon (within-group) and Mann–Whitney (between-group) tests are used.

***Simultaneous Effectiveness Test (MANOVA)***

To test the effect of the e-module on motivation and creativity simultaneously, MANOVA was used. Before conducting MANOVA, prerequisite tests included multivariate normality testing and homogeneity testing of the variance–covariance matrix. Multivariate normality testing was described using Kolmogorov–Smirnov (when the sample size is greater than 50) with a significance level of $\alpha = 0.05$ before proceeding to MANOVA.

## RESEARCH CONTENT

### Product Trial Results

***Content Validation Of The E-Module By The Content Expert***

Content expert validation indicated that the e-module was in the high category, with the following details: material feasibility (content) = 3.45 (high), presentation = 3.57 (high), and integration of PjBL and ethnopedagogy plus creativity = 3.37 (moderate). The overall mean feasibility score by the content expert was 3.45 (high).

**Table 10. E-module Feasibility by the Content Expert**

| Assessment aspect | Mean | Category |
|---|---|---|
| Material feasibility (content) | 3.45 | High |
| Presentation | 3.57 | High |
| Integration of PjBL and ethnopedagogy plus creativity | 3.37 | Moderate |
| Overall mean | 3.45 | High |

The following is a graphical summary of the detailed feasibility assessment of the e-module by the content expert.

***Display and Media Validation of the E-Module by the Media Expert***

Media expert assessment produced a moderate category, with display = 2.83 (moderate) and programming = 2.50 (moderate). The overall mean media feasibility score was 2.60 (moderate).

**Table 11. E-module Feasibility by the Media Expert**

| Assessment aspect | Mean | Category |
|---|---|---|
| Display | 2.83 | Moderate |
| Programming | 2.50 | Moderate |
| Overall mean | 2.60 | Moderate |

The following is a graphical summary of the detailed feasibility assessment of the e-module by the media expert.

***E-Module Validation by Practitioners (Two Validators)***

Practitioner trial results indicated that the e-module was in the high category. The overall mean score for validator 1 was 3.61 (high), and for validator 2 it was 3.95 (high).

**Table 12.** E-module Feasibility by Practitioners

| Assessment aspect | Validator 1 | Validator 2 |
|---|---|---|
| Alignment of learning outcomes and objectives | 4.67 | 4.00 |
| Material structure and presentation | 3.80 | 4.40 |
| Integration of PjBL and ethnopedagogy | 4.29 | 4.14 |
| Questions and answer keys | 3.00 | 4.33 |
| Supporting media (images or videos) | 3.00 | 3.00 |
| Layout | 3.50 | 4.00 |
| Language | 3.00 | 3.75 |
| Overall mean | 3.61 (High) | 3.95 (High) |

The following is a graphical summary of the detailed feasibility results of the e-module from practitioner trials.

***Feasibility of the Lesson Plan (RPP) by Validators***

Lesson plan (RPP) validation (29 items) obtained "Yes" = 22 with a mean score of 3.79 in the high category. Several sub-aspects were in the very high category, but there were sub-aspects that were still low such as "Learning Model and Method", "Learning Resources", and "Closing Activities".

**Table 13. Lesson Plan (RPP) Feasibility by Validators**

| Indicator or sub-aspect | Mean score | Category |
|---|---|---|
| Lesson plan identity | 5.00 | Very High (A) |
| Formulation of indicators and learning objectives | 3.75 | High (B) |
| Learning materials | 5.00 | Very High (A) |
| Learning model and method | 2.50 | Low (D) |
| Learning media | 5.00 | Very High (A) |
| Learning resources | 2.50 | Low (D) |
| Introduction activities (PBL) | 3.75 | High (B) |
| Core activities (PBL) | 4.29 | Very High (A) |
| Closing activities (PBL) | 2.50 | Low (D) |
| Overall | 3.79 | High (B) |

**Feasibility Results of Research Instruments (Motivation and Creativity)**

The motivation and creativity questionnaire instruments underwent content validation before use. The mean score for the motivation instrument was in the range 3.87–4.00, and creativity was 4.00, so both were considered feasible. Empirical validity testing with 24 students showed that all pre-test and post-test items for motivation and creativity had correlations above the r-table value of 0.329, so all items were considered valid.

**Limited Trial Results (Readability)**

A limited trial was conducted with six students with varied ability levels (low, moderate, and high). All students gave a "Very High" category rating, with total scores per student in the range 92–99.

**Table 14. Limited Trial Results (Readability)**

| Student | Total score | Category |
|---|---|---|
| Student 1 | 92 | Very High |
| Student 2 | 99 | Very High |
| Student 3 | 93 | Very High |
| Student 4 | 95 | Very High |
| Student 5 | 97 | Very High |
| Student 6 | 92 | Very High |

**Field Trial Results (Product Effectiveness)**

***Subjects and implementation***

A field trial was conducted in two Grade X classes at SMAN 1 Kampar Timur, namely a control class and an experimental class. The experimental class used the developed e-module, while the control class used conventional learning.

***Improvement in learning motivation (N-gain)***

The number of students in both the control and experimental classes was 30. The mean motivation score in the control class increased from 30.36 (pre-test) to 40.81 (post-test) with an N-gain of 0.15 (low category). In the experimental class, the mean increased from 46.80 to 65.42 with an N-gain of 0.35 (moderate category).

**Table 15. N-gain for Learning Motivation**

| Component | Control class (Pre) | Control class (Post) | Experimental class (Pre) | Experimental class (Post) |
|---|---|---|---|---|
| Number of students | 30 | 30 | 30 | 30 |
| Mean score | 30.36 | 40.81 | 46.80 | 65.42 |
| N-gain | 0.15 | | 0.35 | |
| Category | Low | | Moderate | |

***Improvement in creativity (N-gain)***

For creativity, the control class increased from a mean of 35.00 to 42.80 with an N-gain of 0.12 (low). The experimental class increased from 45.00 to 62.00 with an N-gain of 0.31 (moderate).

**Table 16. N-gain for Creativity**

| Component | Control class (Pre) | Controlclass (Post) | Experimental class (Pre) | Experimental class (Post) |
|---|---|---|---|---|
| Number of students | 30 | 30 | 30 | 30 |
| Mean score | 35.00 | 42.80 | 45.00 | 62.00 |
| N-gain | 0.12 | | 0.31 | |
| Category | Low | | Moderate | |

**MANOVA Prerequisite Test Results**

***Normality Test***

The normality test (Shapiro–Wilk) showed significance values as follows: experimental motivation 0.542, control motivation 0.025, experimental creativity 0.051, and control creativity 0.302.

**Table 17. Normality Test**

| Variable | Class | Statistic | df | Sig. |
|---|---|---|---|---|
| Motivation | Experimental | 0.970 | 30 | 0.542 |
| Motivation | Control | 0.919 | 30 | 0.025 |
| Creativity | Experimental | 0.930 | 30 | 0.051 |
| Creativity | Control | 0.960 | 30 | 0.302 |

***Homogeneity Test of the Variance–Covariance Matrix (Box's Test)***

Box's Test results showed Sig. 0.770, indicating that the homogeneity assumption of the variance–covariance matrix was met.

**Table 18. Box's Test of Equality of Covariance Matrices**

| Box's M | F | df1 | df2 | Sig. |
|---|---|---|---|---|
| 1.173 | 1.139 | 3 | 250976.792 | 0.770 |

***Homogeneity of Variances Test (Levene)***

Levene's test showed Sig. 0.267 for motivation and 1.000 for creativity, indicating that variances between groups were homogeneous.

**MANOVA Test Results**

***Multivariate test (Multivariate Tests)***

The multivariate test on the "Class" factor showed significance of 0.000 across multiple statistics (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root), indicating a significant multivariate difference between the control and experimental classes on the combined motivation and creativity variables.

Table 19. Multivariate Tests

| Statistic | Value | F | Hyp df | Error df | Sig. |
|---|---|---|---|---|---|
| Pillai's Trace | 0.813 | 120.293 | 2 | 57 | 0.000 |
| Wilks' Lambda | 0.187 | 120.293 | 2 | 57 | 0.000 |
| Hotelling's Trace | 4.220 | 120.293 | 2 | 57 | 0.000 |
| Roy's Largest Root | 4.220 | 120.293 | 2 | 57 | 0.000 |

***Follow-up univariate test (Test of Between-Subjects Effects)***

Separately, there was a significant class effect on motivation (F = 33.390, Sig. 0.000) and creativity (F = 29.284, Sig. 0.000).

**Table 20. Test of Between-Subjects Effects**

| Dependent variable | F (Class) | Sig. |
|---|---|---|
| Motivation | 33.390 | 0.000 |
| Creativity | 29.284 | 0.000 |

Based on these results, the experimental class using the PjBL-based e-module and the ethnopedagogy of "Tapai Making" showed higher improvements in motivation and creativity than the control class, and the differences were confirmed as significant through MANOVA.

The results indicate that the project-based and ethnopedagogical digital module received very high ratings from the content expert, media expert, and practitioners, while student readability was also in the very high category. Emphasis on alignment among objectives, content, project activities, and work

instructions is essential so that the module functions as a guide for independent learning, consistent with principles of case-based biology e-module development (Hidayati et al., 2024). When cultural contexts are integrated into the module, students have concrete anchors to interpret concepts and processes, which supports feasibility in both content and pedagogical dimensions. The high feasibility results also suggest that the module provides sufficient clarity in learning objectives, project phases, and evaluation components. In development research, validation by experts and practitioners is critical because it ensures content accuracy, instructional alignment, and media usability before effectiveness is tested. This reinforces that feasibility testing is a necessary gate to ensure the module is suitable for broader use and provides a strong foundation for subsequent effectiveness evaluation.

Selecting conventional biotechnology content through the context of tapai creates learning that is close to everyday life and challenges students to observe, design procedures, and present products. This approach aligns with findings that PjBL is effective when projects require authentic problem solving and structured collaboration (Pangestu et al., 2024). The ethnopedagogical dimension strengthens relevance and learning identity because local values are positioned as sources of knowledge, not merely as anecdotes. Students can interpret fermentation as a scientific process, while also reflecting on local practices and meanings. The process of planning, experimenting, documenting, presenting, and reflecting provides repeated cycles of action and feedback that can reinforce engagement. Such a structure is consistent with the idea that PjBL promotes active involvement and self-regulation when tasks are connected to real-life contexts. Therefore, the tapai project supports the linkage between biotechnology concepts and students' cultural experiences, creating conditions for improved motivation and creativity.

The data show that learning motivation increased more strongly in the class using the PjBL e-module, reflected in higher score gains and N-gain than the control class. This pattern supports evidence that project designs emphasizing goals, moderate challenges, and learning control are associated with improved academic motivation (Wijnia et al., 2024). In project-based learning contexts, motivation also tends to rise when students perceive the project as relevant to their interests and have room to express agency. The module provides a structured pathway that can reduce uncertainty, making students more willing to engage in tasks. In science learning, motivation is reinforced when students see clear connections between effort, process, and outcomes. The ethnopedagogical context may also enhance intrinsic motivation because students engage with familiar cultural practices and interpret them scientifically. Thus, the module likely fosters motivation through relevance, structured guidance, and process-based feedback, so students see biotechnology as a practically useful competence.

Beyond motivation, the results also show improved creativity in the experimental class, as seen in higher scores and higher N-gain than the control group. This finding is consistent with studies reporting that problem-based learning enriched with thinking strategies can promote creativity through open

problem solving and product reflection (Bulut & Aktamis, 2024). In science education, creativity develops when students design procedures, select variables, and validate results, rather than merely following fixed practicum instructions. The PjBL tapai project encourages students to generate ideas about fermentation procedures, modify strategies based on trial results, and communicate findings creatively. Creativity aspects such as fluency and flexibility are trained through brainstorming and exploring alternative solutions in project tasks, while elaboration is strengthened through documentation and structured reporting. In addition, originality can emerge when students propose product improvements, variations, or presentation formats. Therefore, the module environment creates opportunities for divergent thinking while also maintaining scientific accountability through project-based work.

Differences in motivation and creativity outcomes can also be interpreted as the result of alignment between assessment and project characteristics. This study positioned worksheets, rubrics, and presentations as core elements, so students received explicit performance targets. In PjBL science studies, rubrics and presentation activities have been reported to help students formulate ideas, test solutions, and communicate results (Sucilestari et al., 2023). In biotechnology topics, projects demanding tangible products enable students to evaluate results and improve them based on criteria. This cycle supports persistence and engagement and can stimulate creative refinement. Assessment transparency also reduces anxiety because students know what is expected, which can support motivation. When students are guided to document processes and present outcomes, creativity is not only expressed in products but also in explanations and reflections. Thus, the observed differences can be viewed as an outcome of transparent process and product assessment, so students understand standards and are motivated to improve performance.

Using tapai as a project context illustrates how ethnoscience can be elevated into a scientific learning resource. The development of ethnoscience-based biology modules on biotechnology themes confirms that culture–science investigative activities help students connect microorganism concepts with local food processing practices (Rahmalia et al., 2025). This framework aligns with analyses of local-wisdom-based science learning problems that emphasize the need to transform local wisdom into inquiry activities and structured learning resources. By anchoring learning in local practices, students do not start from abstract theory alone, but from observable phenomena and familiar cultural practices. Then, scientific explanations become a tool to understand and critique the practice more deeply. Such contextualization supports not only conceptual understanding but also affective engagement. Therefore, ethnopedagogy contributes to both motivation and creativity by helping students understand that science grows from community practices and can be critically studied in the classroom.

Although the results show improved motivation and creativity, e-module implementation still depends on the technology ecosystem. Device availability, connectivity, and technical support determine smooth access to materials, task submission, and feedback. Studies on digital infrastructure emphasize that the

quality of online learning experiences is influenced by platform readiness, network capacity, and institutional support (Vishnu et al., 2024). In addition, studies on the digital divide show differences in access and digital skills that can affect learning participation and outcomes. If infrastructure is limited, students may face barriers to accessing videos, interactive content, or online forms. Therefore, the success of digital module adoption must be accompanied by planning for technological support and alternative access strategies when needed. This implies that module effectiveness may be moderated by infrastructure readiness, digital literacy, and school support so that digital learning remains inclusive for all students.

Strengthening module effectiveness is also influenced by how digital platforms are used to monitor the project process. Reviews on the role of digital technology emphasize the importance of matching media, interaction, and system support to increase access, personalization, and learning engagement (Haleem et al., 2022). The use of learning management systems designed to foster engagement through scheduled activities and guided discussions has been reported to increase student engagement, suggesting similar potential for PjBL modules when integrated with supportive digital environments. Digital platforms can provide learning traces, enabling teachers to monitor participation, progress, and collaboration. This can help teachers provide timely feedback and adjust support for groups that are struggling. In addition, digital documentation supports project accountability, making it easier for students to reflect on process and outcomes. Therefore, supportive platforms can strengthen project learning by providing learning traces, rapid feedback, and documented collaboration spaces for teachers.

Interpreting improved outcomes also needs to be supported by the quality of instruments and teaching tools used. The development of biotechnology biology e-modules that integrate project activities generally requires clear indicators of motivation and creativity and rubrics that can differentiate student performance levels (Rahmawati, 2024). In biology education research, project-based models have been reported to influence learning interest and learning outcomes when instructions, learning resources, and evaluation are made explicit and aligned with objectives. In this study, instruments were validated and the RPP was also assessed, supporting the validity of the learning process and evaluation. When measurement is accurate and consistent, observed improvements can be interpreted as real learning gains rather than artifacts of measurement error. Therefore, effectiveness claims should always be supported by validated instruments and teaching tools that are aligned with targeted outcomes. This underscores the importance of ensuring instructional tools and assessment instruments are valid, reliable, and aligned with the targeted competency indicators.

Implementing ethnopedagogy-based PjBL requires teachers to act as facilitators who can manage teamwork, practicum safety, and scientific reflection. Experiences of cross-disciplinary PjBL implementation show that collaboration and appropriate problem framing help students interpret relationships among concepts and sustain motivation during projects (Campos-

Roca et al., 2021). However, systematic reviews of schools in rural areas underscore resource constraints, professional support limitations, and technology access barriers that can affect implementation (Hasan et al., 2025). In practical terms, teachers need time, training, and support to guide project processes and facilitate discussions that connect culture with scientific explanation. Teachers also need to manage group dynamics and ensure that all students participate meaningfully. These factors highlight that product feasibility is necessary but not sufficient without teacher readiness and contextual support. Therefore, implementation success requires schools to build collaborative culture, provide adequate project time, and support teachers in designing and evaluating contextual learning.

To broaden impact, capacity strengthening and implementation governance strategies are needed. Development studies and community education research show that repeated training, mentoring, and communities of practice help teachers consistently adopt instructional innovations (Hasan et al., 2025). At the school level, administrative management of digital-module-based learning requires standard operating procedures, task archiving, and feedback mechanisms so that teacher workloads remain realistic (Puspita et al., 2024). Governance is also needed to ensure that digital learning does not create inequality between students with different access and digital skills. Implementation monitoring can help identify obstacles early and ensure ongoing product refinement. In addition, collaboration between teachers and school leaders can support resource allocation and scheduling. Therefore, scaling adoption requires consistent implementation, routine evaluation, and continuous improvement based on data over the long term.

The implications support directions for developing digital teaching materials rooted in local culture while oriented toward 21st-century skills. The development of local-wisdom-based e-modules in other subjects shows that systematic module structures and authentic tasks can increase engagement when contexts are presented explicitly and measurably (Turahmat et al., 2025). In terms of values, integrating religious and cultural aspects into learning tools has been reported to strengthen attitudes and motivation when instruction is aligned with learners' experiences and identity (Zainuddin et al., 2024). Future development can consider adding more interactive elements, project variations, and evaluation mechanisms that capture creative processes more comprehensively. In addition, adaptation for diverse schools will require contextual analysis and flexible design. Therefore, follow-up studies can focus on broader implementation contexts and evaluate sustainability mechanisms within the project process so that ethnopedagogical e-modules can be widely and effectively adapted nationally.

## CONCLUSION

The biotechnology e-module based on Project Based Learning (PjBL) and the ethnopedagogy of "tapai making" was considered feasible because expert and practitioner validation results were in the high to very high categories, and student readability testing indicated a very high category.

The e-module was proven effective in improving learning motivation and creativity. The experimental class showed creativity improvement with an N-gain of 0.31 (moderate category), whereas the control class had an N-gain of 0.12 (low category). MANOVA analysis showed significance of 0.000 in multivariate and follow-up tests, indicating that the e-module had a significant simultaneous effect on motivation and creativity.

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