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The potential of a project-based ethno-STEM biotechnology e-module to promote students' critical and creative thinking skills

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Abstract

Biotechnology education in secondary schools is predominantly theoretical, abstract, and lacks relevance to the local context, making it difficult for students to understand the concepts and resulting in weak critical and creative thinking skills. This study investigates the current state of biotechnology education in high schools, focusing on students' critical thinking and creativity, as well as the integration of local wisdom through the Ethno-STEM approach. The objectives of this preliminary study are: 1) to assess students' critical and creative thinking skills in biotechnology, 2) to identify challenges faced by teachers and students, 3) to explore the integration of local wisdom, and 4) to provide recommendations for developing project-based e-modules. Survey and interview results show that 70% of teachers report students struggling to analyze biotechnology issues, 60% observe low creativity, and 80% note minimal integration of local wisdom. Additionally, 65% of students find it difficult to solve complex problems, and 70% feel the material lacks real-life relevance. These findings were obtained through a descriptive qualitative approach using surveys and interviews, and analyzed through thematic interpretation and descriptive statistics to provide a deeper understanding of the needs and development potential of the e-module. This emphasizes the need for a project-based approach that integrates local wisdom to improve critical and creative thinking skills. This study recommends developing project-based e-modules that integrate local wisdom to engage students and enhance their problem-solving skills, become a foundation for future research and the development of more contextual and creative learning methods.

Abstrak. *Pembelajaran bioteknologi di sekolah menengah dominan bersifat teoretis, abstrak, dan kurang berkaitan dengan konteks local, sehingga peserta didik kesulitan memahami konsep, serta lemahnya keterampilan berpikir kritis dan kreatif. Penelitian ini mengkaji kondisi pembelajaran bioteknologi di SMA, dengan fokus pada keterampilan berpikir kritis dan kreatif siswa, serta integrasi kearifan lokal melalui pendekatan Ethno-STEM. Tujuan dari penelitian pendahuluan ini adalah: 1) menilai keterampilan berpikir kritis dan kreatif siswa dalam pembelajaran bioteknologi, 2) mengidentifikasi tantangan yang dihadapi guru dan siswa, 3) mengeksplorasi potensi integrasi kearifan lokal, dan 4) memberikan rekomendasi pengembangan e-modul berbasis proyek. Hasil survei dan wawancara menunjukkan bahwa 70% guru melaporkan kesulitan siswa dalam menganalisis isu bioteknologi, 60% mengamati rendahnya kreativitas, dan 80% mencatat minimnya penerapan kearifan lokal. Selain itu, 65% siswa merasa kesulitan memecahkan masalah kompleks, dan 70% merasa materi tidak relevan dengan kehidupan sehari-hari mereka. Temuan ini diperoleh melalui pendekatan deskriptif kualitatif dengan menggunakan survei dan wawancara, serta dianalisis melalui interpretasi tematik dan statistik deskriptif untuk memberikan pemahaman yang lebih mendalam mengenai kebutuhan dan potensi pengembangan e-modul. Hal tersebut menegaskan perlunya pendekatan berbasis proyek yang mengintegrasikan kearifan lokal untuk meningkatkan keterampilan berpikir kritis dan kreatif. Penelitian ini merekomendasikan pengembangan e-modul berbasis proyek yang mengintegrasikan kearifan lokal untuk meningkatkan keterlibatan siswa dan keterampilan pemecahan masalah, menjadi dasar bagi penelitian selanjutnya dan pengembangan metode pembelajaran yang lebih kontekstual dan kreatif.*

A. Introduction

Education in the current era of globalization is faced with increasingly complex challenges, which not only demand the enhancement of students' academic knowledge but also their critical and creative thinking skills. In the field of biotechnology, one of the continuously developing branches of science, students need to be trained to understand highly technical scientific concepts and be able to relate them to real-world issues. Critical and creative thinking skills are essential for students to analyze biotechnology issues related to health, agriculture, the environment, and other social issues (OECD, 2019; Zohar & Dori, 2003). However, in practice, in many countries, including Indonesia, there remains a gap between theoretical learning and practical application in biotechnology education (Faisal & Martin, 2019). One approach that can bridge this gap is project-based learning that integrates the STEM (Science, Technology, Engineering, and Mathematics) approach with local wisdom, known as Ethno-STEM (Grigg & Riedel, 2019).

The implementation of project-based learning with the Ethno-STEM approach in biotechnology education not only helps students understand scientific concepts but also connects learning to their local context, creating a more relevant and applicable learning experience (Barata et al., 2021). Project-based learning (PjBL) integrated with technology, particularly e-modules, offers innovative solutions to support more interactive and independent learning (Wang & Lee, 2021). However, despite the great potential of developing e-modules based on Ethno-STEM projects, research on its implementation and development needs at the secondary school level in Indonesia is still limited (Purwanto et al., 2020). Therefore, this preliminary study was conducted to identify the needs and potential for developing biotechnology e-modules based on Ethno-STEM projects, focusing on enhancing students' critical and creative thinking skills in secondary schools. This research was conducted using surveys and interviews to collect data from teachers and students at a local high school. It is expected that the results of this study can provide a clearer picture of the challenges, needs, and potential for developing Ethno-STEM project-based e-modules that can enhance students' critical and creative thinking skills in biotechnology education.

In Indonesia's national education curriculum, critical and creative thinking skills are primary objectives to prepare the younger generation to face increasingly complex global challenges (Kemendikbudristek, 2022). These skills are necessary in the context of biotechnology, a field of science that touches various aspects of life, such as health, food, and the environment. However, despite the awareness of the importance of developing these skills, biotechnology education in many schools still focuses on theoretical approaches and less connects the material with students' daily lives (Simon et al., 2022). This results in low interest and motivation among students in learning biotechnology, as the material is considered too abstract and not relevant to their local context (Fensham, 2008). The statement shows that biotechnology material is often seen as too abstract because teachers only explain it theoretically, without providing real, hands-on activities. Students only listen to explanations without seeing or trying the processes themselves, making it difficult for them to understand the concepts. In addition, the material is rarely connected to students' local culture or daily life, such as traditional food fermentation processes that are actually very familiar in their environment. Since the content is not linked to things students know, it feels distant and irrelevant, causing them to lose interest and motivation to learn. Therefore, developing more contextual teaching methods, such as project-based e-modules with the Ethno-STEM approach, is crucial to improving the quality of learning and students skills.

Project-based e-modules using the Ethno-STEM approach have proven effective in enhancing students' critical and creative thinking skills by offering contextual, interactive, and meaningful learning experiences. By connecting science content—particularly conventional biotechnology—with local culture and real-world problems, students are encouraged to analyze, evaluate, and develop solutions independently and collaboratively. Research by Wulandari et al. (2021) found that project-based e-modules significantly improve critical thinking skills by promoting active student engagement in problem-solving processes. Similarly, Sari and Astuti (2022) revealed that the Ethno-STEM approach supports the development of student creativity by integrating local cultural practices into STEM learning. Through project activities, students not only gain a deeper understanding of scientific concepts but are also trained to think logically, innovatively, and reflectively. This approach makes learning more active, relevant, and impactful in fostering essential 21st-century skills.

Integrating local wisdom into biotechnology education is an important step in creating learning relevance for students, thereby enhancing their understanding of the material being taught (Sumarni & Sudarmin, 2020). Learning that connects material with local wisdom can increase students' sense of ownership of knowledge and strengthen their connection with their culture and environment (Tytler, 2020; Ramdiah et al., 2020). However, despite much theoretical discussion on integrating local wisdom into education, its implementation in the classroom remains limited (Rahmawati & Ridwan, 2022). Therefore, this research focuses on identifying the needs and potential for developing Ethno-STEM project-based e-modules to address this gap.

Based on the literature review, there have been many studies examining PjBL and the application of STEM in classrooms, as well as some discussing the

implementation of Ethno-STEM in education (Grigg & Riedel, 2019). However, research integrating local wisdom into biotechnology education with the Ethno-STEM approach is still very limited. Most previous studies have focused on theory and learning models without developing practical solutions that can be implemented in the classroom, such as the development of project-based e-modules. Additionally, most existing research has not directly assessed the impact of project-based learning with the Ethno-STEM approach on students' critical and creative thinking skills in the context of biotechnology.

The main goal of this research is to identify the needs and potential for developing biotechnology e-modules based on Ethno-STEM projects that can enhance critical and creative thinking skills in high school students. Specifically, this research aims to:

1) Assessing the condition of students' critical and creative thinking skills in biotechnology material at the secondary school level.
2) Identifying the challenges and needs faced by teachers and students in biotechnology material.
3) Exploring the potential to integrate local wisdom into biotechnology material through the Ethno-STEM approach.
4) Provide recommendations for developing project-based e-modules that can facilitate the enhancement of students' critical and creative thinking skills.

This research aims to fill the gap in previous studies by developing a new concept in biotechnology teaching that integrates the Ethno-STEM approach. By identifying the needs and potential for developing e-modules in this context, this research supports the technology-based approach in education and introduces a more relevant local dimension for students. This research attitude not only supports but also seeks to correct the shortcomings in the implementation of current teaching methods, particularly in the field of biotechnology.

B. Material and method

In this study, the method used was a qualitative descriptive approach with data collection through surveys, questionnaires, interviews and observations (Creswell, 2014; Patton, 2015). This approach is chosen to provide an in-depth understanding of the existing problems and to explore the perceptions and experiences of both students and teachers regarding biotechnology education and the integration of local wisdom (Bogdan & Biklen, 2007).

The research subjects consisted of grade XII high school students studying biotechnology and biology teachers in Bandung City. Data is collected through questionnaires to measure the perceptions of students and teachers regarding critical and creative thinking skills, as well as the integration of local wisdom (Dillman et al., 2014), semi-structured interviews to explore challenges in biotechnology education and local wisdom integration (Kvale, 2007), and observations to observe the application of these skills in the classroom (Ary et al., 2010).

The data is analyzed using a qualitative approach with thematic analysis to identify issues related to critical and creative thinking skills, as well as local wisdom (Braun & Clarke, 2006), and a quantitative approach with descriptive statistics to calculate the percentage of responses from the questionnaires.

The research procedure begins with the development of instruments and sample selection, followed by data collection, data analysis, and concludes with reporting of the research findings along with recommendations for e-module development. The instruments in this study include: (1) a student questionnaire and (2) a teacher questionnaire, both developed based on indicators of critical and creative thinking adapted from the OECD framework. The student questionnaire consists of 15 items in the form of a Likert scale (1–5), categorized into three indicators of critical thinking (analyzing, evaluating, decision making) and two indicators of creative thinking (originality and idea generation). The teacher questionnaire comprises 10 items, focusing on observations of students' thinking skills and the integration of local wisdom in learning. The interview guidelines are prepared with semi-structured questions aligned with the same indicators, allowing for in-depth exploration. The research sample consists of 36 12th-grade students and 4 biology teachers selected through purposive sampling at a private high school in Bandung City. Questionnaire data are analyzed using descriptive statistics (percentages and means), while qualitative data from interviews are analyzed using thematic analysis through a process of coding and categorization to identify patterns and insights.

This study was conducted during one odd semester at the selected senior high school, with data collection taking place from the fourth week of November to the third week of December 2024.

C. Results and discussion

The preliminary study was conducted through surveys and interviews with teachers and students at a local high school. The purpose of this study was to assess students' critical and creative thinking skills and the integration of local wisdom in biotechnology learning. The assessment of biotechnology material needs was conducted using a Likert scale questionnaire (1–5) consisting of six statements. Each item represents indicators of conceptual understanding, material relevance to real-life contexts, and student interest in biotechnology subtopics such as fermentation, genetic engineering, and vaccine production. Data were collected from 36 students and analyzed descriptively using mean score calculations and the percentage of positive responses. A mean score below 3.0 on certain

subtopics indicated areas where content reinforcement is needed. The instrument table and summary of results are included in the appendix to strengthen the clarity of the methods and findings. The data collected provided valuable insights into the challenges and needs for developing an innovative project-based e-module using the Ethno-STEM approach. Below is a comprehensive analysis of the data obtained:

1. Results of Teacher and Student Surveys

The surveys aimed to explore teachers' and students' perspectives on critical thinking, creativity, and the application of local wisdom in learning. The measurement of challenges faced by teachers and students was carried out using two approaches. First, quantitatively through a Likert scale questionnaire (1–5), where the percentage value was calculated by dividing the number of "agree" and "strongly agree" responses by the total number of respondents (36 students and 4 teachers). For example, 70% of students reporting difficulty in analyzing biotechnology content means that 25 out of 36 students selected agree or strongly agree. Second, qualitatively through semi-structured interviews, which were analyzed thematically to provide deeper context to the identified challenges. This dual approach ensured data triangulation between survey results and field findings. The findings from these surveys are presented in Figure 1 and Figure 2.

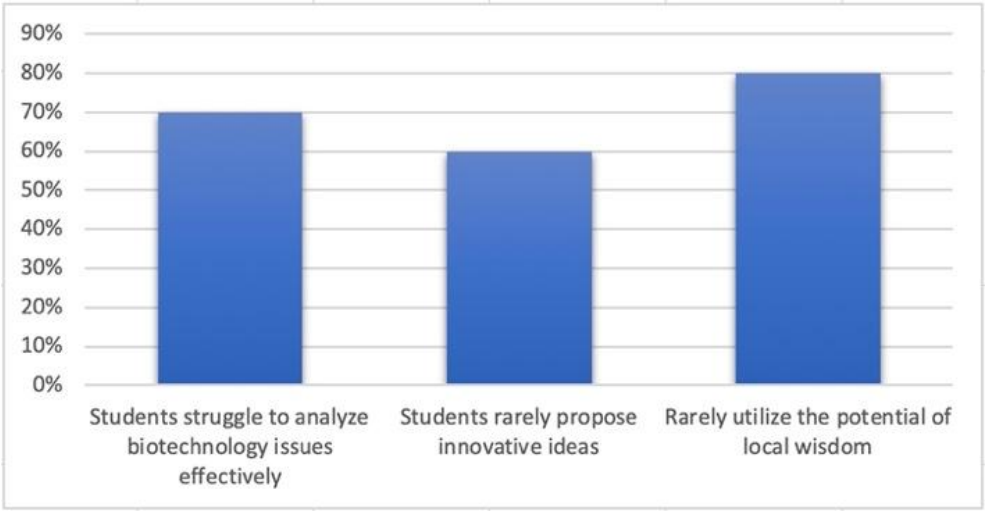

Figure 1 Survey results: Teachers' perspectives on critical thinking, creativity, and integration of local wisdom

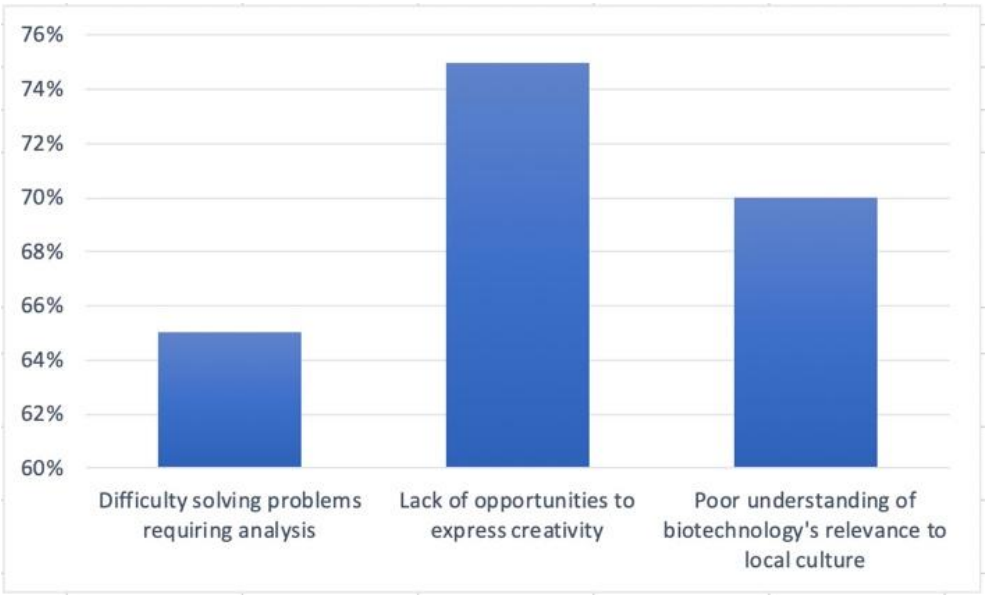

Figure 2 Survey results: Students' perspectives on critical thinking, creativity, and relevance of local wisdom

2. Interview Data

Interview data were collected from four biology teachers and thirty-six 12th-grade students selected through purposive sampling at a private senior high school in Bandung City. The teachers were actively teaching biology subjects, while the students were

selected based on diverse interests and levels of participation in learning. The interviews were conducted using a semi-structured format and analyzed using a thematic approach. The main themes identified from the interviews are summarized in Table 3 and Table 4.

Table 1 Summary of teacher interviews

Main topic	Teacher responses
Project-based learning materials	"Current materials are too theoretical. Students need more practical, project-based activities."
Integration of local wisdom	"We rarely integrate local wisdom due to limited supporting modules."
Use of digital learning facilities	"Digital facilities are available but not optimally utilized for innovative teaching."

Table 2 Summary of student interviews

Main topic	Student responses
Understanding biotechnology concepts	"Sometimes I struggle to understand biotechnology lessons because they are not connected to everyday life."
Learning motivation	"Learning would be more exciting if we could create real projects, especially if they relate to our local area."
Access to technology-based materials	"We want interactive materials accessible through devices like phones or laptops."

Based on the analysis of survey results from teachers and students, as well as interviews with both groups, several important issues related to biotechnology education were identified that require further attention. This discussion will integrate the survey findings to provide a more comprehensive understanding of the challenges faced in biotechnology education and offer recommendations for developing project-based learning that integrates local wisdom.

First, the teacher survey results indicated that the majority of teachers (70%) believed that students struggle with analyzing biotechnology problems effectively. This is further attributed to the learning approach, which tends to emphasize theory rather than its application in real-life contexts. Education that is too focused on theoretical aspects often neglects opportunities for students to solve real-world problems that require critical thinking skills. In line with the research conducted by Hmelo-Silver (2004), project-based learning approaches can enhance students' analytical skills by challenging them to solve problems relevant to their everyday lives. Therefore, project-based biotechnology education is necessary for students to develop critical thinking skills in more applicable and real contexts.

In addition, the majority of teachers also considered students' creative ideas to be still low, with 60% of teachers stating this. Students' creative ideas in biotechnology education can be improved if they are given the opportunity to explore new ideas and innovate. The use of design-based and innovation-based approaches in biotechnology education, as suggested by Robinson (2015), will help students design biotechnology solutions that are not only based on theory but also on their creative ideas. Therefore, a more interactive approach, such as design-based projects, needs to be implemented to allow students to innovate in solving practical problems.

Furthermore, the survey results showed that a majority of teachers (80%) acknowledged that local wisdom is rarely integrated into biotechnology education. This indicates a gap between the material taught and the cultural context and the local life of students. As emphasized by Syahfitri et al. (2024), integrating local wisdom in education can increase student engagement, especially when the material taught is relevant to their life experiences. Techniques such as traditional fermentation or regional food processing could serve as concrete examples to contextualize biotechnology concepts. In this way, students not only learn about biotechnology theory but also understand how these principles can be applied in their cultural context.

The form of local wisdom integration needed in biotechnology education refers to traditional practices and knowledge that directly relate to scientific concepts, such as the fermentation processes of tape and tempeh, herbal medicine preparation (jamu), compost production, or natural waste processing. This integration not only strengthens students' connection to their culture and environment but also builds a bridge between modern science and local traditions (Sari et al., 2023). Learning activities rooted in local contexts reinforce ethical, ecological, and sustainability values that lie at the core of the Ethno-STEM approach. Therefore, the development of e-modules should consider relevant local practices aligned with biotechnology topics to enhance students' understanding and sense of ownership of the content.

The student survey results showed that 65% of students felt they had difficulty solving complex biotechnology problems. Students tend to be less familiar with project-based learning, which can train their analytical skills. This confirms that biotechnology education in schools focuses more on theory and less on practice, which could enhance critical thinking and

problem-solving skills. Therefore, a project-based approach that challenges students to solve real-world problems is essential, as suggested by Fensham (2009). This approach will enable students to confront complex and relevant real-world problems, thus helping them develop better analytical and creative skills.

Related to creative ideas, 75% of students felt that they were not given enough opportunities to express their creative ideas in biotechnology education. They felt that the current learning approach does not provide sufficient space for them to innovate. This aligns with Robinson's (2015) findings, which state that the lack of exploratory activities in education limits students' creative potential. Therefore, a more project-based approach, where students can design and create new biotechnology solutions, is essential to enhance their creativity.

Furthermore, 70% of students felt they were unable to connect biotechnology material with everyday life, especially in the context of local cultural values. They felt that the material taught was not relevant to their culture and life, which made it difficult for them to understand the connection between biotechnology and the real world. Research by Devkota & Timilsena (2024) and Holmes et al. (2021) shows that integrating local contexts in biotechnology education can improve students' understanding and engagement with the material taught. Therefore, it is important to integrate local wisdom into biotechnology education so that students can see how biotechnology principles relate to their lives.

Based on these findings, the development of a project-based e-module with an Ethno-STEM approach is highly recommended. This e-module is expected to integrate local wisdom, such as traditional fermentation techniques, making biotechnology material more relevant and contextual for students. Design-based projects should also be introduced to provide students with the opportunity to design innovative and creative biotechnology solutions. Additionally, this e-module should be designed to leverage digital technology, ensuring that the learning material can be easily accessed by students through their devices, according to their technological preferences and needs. This is crucial for improving student engagement and the effectiveness of biotechnology education in schools.

The proposed e-module is designed to implement a PjBL approach combined with Ethno-STEM principles. The module should include contextual projects such as: (1) studies on local food fermentation (e.g., tape and tempeh), (2) creation of educational videos about traditional biotechnology processes, (3) designing simple tools for producing bio-pesticides from local materials, and (4) conducting interviews with local biotechnology-based entrepreneurs. These projects are structured following the PjBL stages outlined by Hmelo-Silver (2004) which include problem identification, planning, exploration, resolution, and reflection. Through this approach, the e-module not only facilitates conceptual understanding but also fosters 21st-century skills such as collaboration, creativity, and digital literacy.

Thus, to improve the quality of biotechnology education, changes need to be made in teaching approaches, with a focus on the use of design-based projects, the integration of local wisdom, and the utilization of technology to create more relevant, creative, and applicable learning materials. This will help students develop the critical and creative thinking skills needed to solve real-world biotechnology problems.

D. Conclusion

The findings of this study reveal significant challenges in biotechnology education, particularly related to students' critical and creative thinking skills, as well as the low integration of local wisdom. Data shows that 70% of teachers report that students struggle to analyze biotechnology problems, 60% state that students rarely propose creative ideas, and 80% acknowledge that the integration of local wisdom in teaching is very limited. Students also feel challenged, with 65% struggling to solve problems requiring analysis, and 75% feeling they are not given space to express their creativity. To address these issues, the development of a project-based e-module with an Ethno-STEM approach is highly recommended. This e-module will link biotechnology learning with local culture and promote critical and creative thinking skills through projects that are relevant to real-world problems. The use of digital tools is also crucial to facilitate easy access to materials according to students' technological preferences. This change in teaching approach is expected to enhance students' analytical, creative, and problem-solving skills. Future research could focus on testing the effectiveness of this e-module and the application of Ethno-STEM to enhance students' critical and creative thinking skills.

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