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Research Article

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Enhancing students' critical thinking skills: Developing a biology practicum module using the PjBL model by integrating local Banana Goroho

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ABSTRACT

The lack of integration of project-based learning (PjBL) in nutrition education, especially in the context of local foods that have great potential but have not been widely explored, especially the use of (*Musa acuminafe*) as a practicum material, which is an alternative carbohydrate source typical of the Minahasa region. This study aims to develop a practicum module that enhances thinking skills using the PjBL model by testing the nutritional content of local foods of the Minahasa community (local banana Goroho/*Musa acuminafe*). This study employed a research and development (R&D) approach using the ASIE model (Analyse, Design, Implement, and Evaluate). The research subjects were undergraduate Biology students at Manado State University, with a sample of 30 students enrolled in the first semester of the 2024/2025 academic year. The research instruments included module validation sheets, student response questionnaires, and critical thinking skills tests to assess the effectiveness of the developed practicum module with the N-Gain score. The validation results from material and media experts show that the developed module is very valid, with scores reaching 96.166% and 95.6%, respectively. Furthermore, testing of students' critical thinking skills showed very good results, with an average score reaching 85.51%. In addition, student responses to this practicum module were also very positive, with an average score of 91.074%, which indicates a very practical category. These findings confirm the module's effectiveness in enhancing students' critical thinking skills (N-Gain=0.71, high category) and its relevance in the context of locally-based nutrition education. This research significantly contributes to the development of innovative and community-relevant learning methods and can serve as a reference for further research in education and nutrition.

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INTRODUCTION

The digestive system is a course that examines biological concepts related to the structure and function of digestive organs, the processes of digestion and nutrient absorption, as well as the body's responses to changes in internal conditions and nutrient availability (Ahİ, 2017; Arzu et al., 2020). In this course, students are required to analyze problems related to fundamental concepts of the digestive system, including health issues and digestive disorders, through practicum activities. Through these practicum activities, students are expected to develop thinking skills that support their ability to solve problems encountered in their surrounding environment (Susanti et al., 2024). Therefore, students must possess critical thinking skills to analyze various phenomena related to the digestive system observed during learning activities. Critical thinking requires students to engage in reflective thinking so that they are able to determine appropriate solutions to the problems they face based on scientific knowledge and evidence (Rico et al., 2023; Dias-Oliveira et al., 2024).

Critical thinking skills can also be applied in procedural learning, such as practicum-based instruction, enabling students to understand more comprehensively the facts embedded within conceptual knowledge (Shen & Feng, 2024). Practicum-based learning in digestive system topics requires students to connect empirical findings obtained during observation with theoretical concepts previously learned. Consequently, this type of learning demands higher-order thinking skills to integrate these facts effectively, allowing the concepts to be accurately and meaningfully understood (Kwangmuang et al., 2021). Every individual inherently has the potential to develop critical thinking skills; however, not all individuals are able to apply them effectively in problem-solving situations. Individuals with strong critical thinking abilities are capable of analyzing problems and making well-reasoned decisions based on logical considerations and available evidence (Makafui et al., 2021; Rong, 2025).

Students have diverse views about biology, but many experience difficulties, especially in topics like genetics. Contributing factors include limited English proficiency, poor reading habits, an unsupportive learning environment, and the teacher's role in the learning process. Many students complain about the complexity of biology and the difficulty of understanding technical terms. This leads some to lose interest, ultimately preventing them from pursuing higher-level studies in related fields. Ndayambaje et al. (2021) identified inappropriate teaching methods as a contributing factor to low student achievement in biology. Furthermore, the complex nature of the material is a major cause of students' difficulties in learning various biology topics (Fauzi et al., 2021). While conventional approaches can be effective in conveying extensive material to large groups of students without hearing impairments, Haile et al. (2024) noted that one-way communication patterns tend to make students passive and hinder their motivation, confidence, and enthusiasm for learning. Teaching deaf students requires a range of impactful teaching approaches that foster meaningful learning, project-solving, and critical thinking. When deaf classrooms are not stimulated and enriched with effective teaching facilities and techniques that can compensate for hearing loss, their academic performance tends to decline to alarming levels for students, parents, teachers, and other stakeholders (Adigun, 2020).

The lack of critical thinking skills among college graduates is a concern for both educators and employers. Mastery of so-called "soft skills" such as critical thinking can be applied across a wide range of content areas, including biology (Nelson et al., 2018). With improved critical thinking skills, biology students will be better prepared to solve problems as engaged and productive citizens (Muhfahroyin et al., 2023). Scholars across disciplines have also long emphasized the relevance of these skills in education (Ennis, 1984; Bezanilla et al., 2019). Efforts to find the best strategies for teaching critical thinking in higher education have been extensively researched (Byrnes & Dunbar, 2014; Cargas et al.,

2017). However, teaching critical thinking remains a significant challenge, with numerous studies demonstrating the need for instructor training (Wartono et al., 2018; Leasa et al., 2020). Debate continues regarding the most effective methods, with some supporting a generalist approach. Critical thinking skills are related to higher-order cognitive skills, such as analyzing, synthesizing, and evaluating (van der Zanden et al., 2020). The learning environment must support students' acquisition of critical thinking skills as tools they use to construct their own understanding (Almulla, 2023). Lecturers need to consider empowering students' argumentation and critical thinking skills through the implementation of appropriate learning models (Hasnunidah et al., 2019). Previous findings indicate that the use of active learning strategies has the potential to improve critical thinking skills and provide initial evidence that first-year students and underrepresented student groups tend to benefit more (Styers et al., 2018).

Therefore, it is essential to explicitly link students' critical thinking skills with practicum-based learning activities, particularly in biology education. Practicum activities provide an authentic context in which students can engage in observing phenomena, formulating questions, designing experiments, analyzing data, and drawing evidence-based conclusions—all of which are core components of critical thinking. However, several obstacles often limit the effectiveness of practicum activities in fostering these skills, including the dominance of verification-style laboratories, limited time allocation, insufficient guidance in inquiry and argumentation, and lecturers' lack of training in facilitating higher-order thinking during laboratory work. As a result, practicum sessions frequently focus on procedural completion rather than reflective reasoning and problem-solving. Addressing these challenges requires the integration of inquiry-oriented and active learning-based practicum designs that deliberately scaffold critical thinking processes, enabling students to meaningfully connect theory and practice while developing transferable skills essential for academic and professional success.

In addition to the theories and concepts taught in the digestive system, practical activities are crucial. Practical activities serve a significant purpose: to bridge the theories learned in class with their application in real-world practice. Through practical activities, students are not only able to adapt and prove these theories, but also equipped with other skills and abilities that can only be obtained through direct experience while carrying out practical work, but also empower students to be qualitatively and functionally educated (Osuafor & Amaefuna, 2016). Practical activities are important learning activities that support the success of Biology learning. Through practical activities, students' cognitive, psychomotor, and affective learning outcomes can develop optimally (Ramadhan & Suyanto, 2020). Effective implementation of practical work requires the availability of clear and informative guidebooks to facilitate the process (Chala, 2019).

The results of the needs analysis indicate that experimental activities related to the digestive system, particularly those involving trials of local Minahasan food materials, have never been implemented. This condition is primarily due to the limited availability of relevant and contextualized practicum guidelines, resulting in students' lack of access to laboratory modules that integrate local food materials into practicum activities. On the other hand, the Minahasa region possesses abundant natural resources, such as goroho bananas (*Musa acuminafe*), which have significant potential as test materials for analyzing nutritional and vitamin content relevant to digestive system concepts. However, this potential has not been optimally utilized in the learning process, causing students' learning experiences to remain largely theoretical and less meaningful. Therefore, the development of a practicum guidance module based on local food materials is an urgent need to address this gap. This module is expected to bridge theory and practice, enhance the quality of practicum activities, and foster students' contextual knowledge and practical skills. Furthermore, the use of local materials in practicum activities not only enriches

students' learning experiences but also raises awareness of the potential of surrounding natural resources, thereby making biology learning more relevant, applicable, and sustainable.

Several studies related to the Goroho banana variety grown in several countries, such as Brazil, Ecuador, and Malaysia have shown that this plant contains several secondary metabolite compounds such as phenols, tannins, terpenoids, and saponins (Suniati & Purnomo, 2019), and has very useful biological activities such as antioxidants, antifungals, and antimicrobials (Mihai et al., 2024; Mekawy et al., 2025). Goroho bananas, known as one of the traditional foods rich in nutritional value, are an excellent alternative as a substitute carbohydrate source in the daily lives of the Minahasa people. By utilizing Goroho bananas as a practical material in learning, we can not only improve students' understanding of the digestive system but also help preserve and cultivate long-standing local wisdom. Therefore, it is hoped that this developed practical module will not only provide significant support for teachers and students in the Biology learning process, but also serve as an effective means to promote and introduce the potential of local genetic resources in Minahasa to the wider community. This module will simplify the use of practical tools and materials, making them easily accessible and usable by all parties involved. Thus, the developed guidance module focuses on project-based food ingredient testing, utilizing local food ingredients. Through this approach, it is hoped that students will not only gain in-depth practical knowledge but also be able to directly experience the benefits of abundant local resources, while contributing to the preservation of regional culture and traditions.

Learning activities and practicums are inseparable from the assistance of a learning model that facilitates the achievement of learning objectives, including the use of the project-based learning (PjBL) model (Sauter et al., 2022). PjBL is an inquiry-based teaching approach that encourages students to build knowledge through implementing meaningful projects and producing tangible products (Waite, 2020). According to Krajcik & Shin (2014), there are six main characteristics of PjBL: the presence of triggering questions, a focus on learning objectives, involvement in educational activities, collaboration between students, the use of supporting technology, and the creation of tangible artifacts. Of all these characteristics, the creation of artifacts that solve authentic problems is considered the most important and distinguishes PjBL from other student-centered learning models such as problem-based learning (Markula & Aksela, 2022). Compared to traditional teacher-led learning, PjBL has been shown to produce higher academic achievement (Chen, 2018). Furthermore, PjBL has been shown to improve students' critical thinking and questioning skills (Sasson et al., 2018). There is also some evidence that PjBL can contribute to the development of students' intra- and interpersonal competencies (Wijnia, 2025). This process requires students to work collaboratively to find solutions to real-world problems through the integration, application, and development of knowledge. The role of instructors and community members (e.g., clients) is generally that of facilitators, providing feedback and support to students. Several review studies have focused more on the application of PjBL in higher education.

PjBL addresses the fundamental challenges of increasing student motivation, mastery of subject matter, and finding applications of what they have learned in various situations. Using PjBL methods, students demonstrate improvements in self-confidence, laboratory technical skills, and interest in science-related fields. Most importantly, students demonstrate high levels of performance and satisfaction (Gao et al., 2024). However, in terms of impact, only a few studies have evaluated the influence of PjBL on cognitive (e.g., knowledge) and affective (e.g., motivation) aspects. Ralph (2015), in his review of 14 PjBL studies in the STEM field, found that this model can improve students' knowledge and skills. Reis et al. (2017) reviewed PjBL studies in engineering education using a bibliometric approach (e.g., keyword analysis) showed that the three most popular keywords were project-based learning, engineering

education, and problem-based learning. Several studies also reported improvements in students' academic knowledge, skills, and motivation through PjBL, despite challenges such as the time-consuming process. However, this review has important limitations because it does not clearly differentiate between project-based learning and problem-based learning (Guo et al., 2020). Furthermore, PjBL has been shown to deepen learning and develop work skills for students through active engagement with learning materials (Pranjol et al., 2024).

The novelty of this study lies in the integration of project-based learning (PjBL) with practicum-based laboratory activities using local food resources. Unlike previous studies that implemented PjBL only as a learning model, this research develops a structured practicum module that systematically guides students through the PjBL stages in laboratory learning. The use of PjBL is justified because nutritional testing requires authentic scientific processes such as problem identification, experiment design, data analysis, and result communication. In this study, PjBL is applied not merely to conduct experiments but to develop a student project focused on analyzing carbohydrate and vitamin C content of Minahasa's local Goroho banana (*Musa acuminafe*) in relation to digestive system concepts. Furthermore, previous research has rarely utilized local food materials as the core substance of student projects. This study emphasizes local wisdom by positioning the Goroho banana not only as an experimental object but also as a meaningful learning resource. The resulting practicum module serves as an innovative learning product that supports critical thinking skills through contextual, project-oriented laboratory activities. The objective of this research is to develop a practicum module that enhances thinking skills using the PjBL model by testing the nutritional content of local foods of the Minahasa community (local banana Goroho/*Musa acuminafe*).

RESEARCH METHODS

This research is classified as development research employing the ASIE model (analyse, design, implement, evaluate). The development process encompasses a systematic sequence of activities, including needs analysis, product design, implementation, and evaluation of the developed product. The ASIE model, as proposed by Zain et al. (2016), offers several advantages that support its application in this study. It provides a practical and flexible design framework that can be adapted to current educational contexts, integrates both formative and summative assessment within learning activities, and is specifically designed to address contemporary educational demands. Furthermore, the ASIE model supports the development of 21st-century skills, including creativity, collaboration, communication, and problem-solving (4Cs), making it highly relevant for preparing students to meet modern learning challenges.

The research subjects were all undergraduate Biology students at Manado State University in the first semester of the 2024/2025 academic year. The purpose of this study was to test the effectiveness of the developed module and to assess students' critical thinking skills through a practicum-based test involving 30 students. The participants were selected using a total sampling technique, in which all students enrolled in the course were included as research subjects. The learning process was conducted over six instructional sessions, starting with a pre-test, followed by a series of project-based learning–oriented practicum activities, and concluding with a post-test. The research instruments consisted of an expert validation sheet, a student response questionnaire, and observation sheets. Prior to implementation, all research instruments were validated by three experts from the fields of genetics, botany, and biology education affiliated with Universitas Negeri Malang and Universitas Negeri Manado to ensure content validity and relevance. The critical thinking skills instrument was developed based on

the indicators proposed by Ennis (1987), namely elementary clarification, basic support, inference, advanced clarification, and strategy and tactics. Module validity assessment criteria can be seen in Table 1. Module practicality assessment criteria can be seen in Table 2.

Table 1. Module Validity Assessment Criteria

Percentage	Criteria
90-100%	Very Valid (can be used with minor revisions)
75-89%	Valid (can be used with minor revisions)
65-74%	Fairly Valid (can be used, but with major revisions)
40-64%	Less Valid (not recommended for use due to the need for major revisions)
0-39%	Invalid (cannot be used)

(Watoni et al., 2022)

Table 2. Module Practicality Assessment Criteria

Percentage	Criteria
81-100%	Very Practical
61-80%	Practical
41-60%	Fairly Practical
21-40%	Less Practical
0-20%	Not Practical

(Hadira et al., 2024)

Data on the effectiveness of the e-module related to mastery of critical thinking skills was obtained through pre-test and post-test. Measurement of students' critical thinking skills can be done by comparing the results of the pre-test and post-test analyzed through the N-Gain test adapted from Hake (1998) which can be seen in equation 1. Module Effectiveness Criteria Based on N-gain can be seen in Table 3.

$$N - gain = \frac{Pretest\ score - post-test\ score}{100 - post-test\ score} \quad (1)$$

Table 3. Module Effectiveness Criteria Based on N-gain

Value Range	Criteria
0.70 < g ≥ 1.00	High
0.3 < g ≥ 0.70	Medium
0.00 < g ≥ 0.30	Low

This study uses research development using the ASIE model. The ASIE development model consists of four stages, including analysis, strategy, implementation, and evaluation (Table 4). Research design and method should be clearly defined. The first stage focuses on identifying learning needs and existing problems in practicum-based learning of the digestive system. At this stage, an analysis was conducted on students' characteristics, course learning outcomes, and the gap between expected competencies and actual learning conditions. The analysis indicated that students faced difficulties in connecting theoretical concepts with empirical findings during practicum activities and showed limited critical thinking skills. These findings highlighted the need for a structured practicum module that integrates project-based learning (PjBL) to promote active learning and higher-order thinking.

The second stage involves designing the practicum module based on the results of the needs analysis. This stage includes formulating learning objectives, organizing practicum materials, designing project-based learning activities, and developing assessment instruments aligned with critical thinking indicators. The module was designed to guide students through systematic project stages, including

problem identification, experimental procedures, data analysis, and result communication, ensuring the integration of theoretical knowledge and practical experience.

The third stage is the implementation of the developed practicum module in the digestive system course. During this stage, students participated in project-based learning activities by planning and conducting practicum experiments, collecting and analyzing data, and presenting project outcomes. The lecturer acted as a facilitator to support collaboration, inquiry, and reflection. This stage aimed to examine the practicality of the module and its effectiveness in improving students' critical thinking skills in real classroom settings.

The fourth stage involves evaluating the effectiveness of the practicum module after implementation. Evaluation was carried out through expert validation, student response questionnaires, and pre-test and post-test assessments to measure improvements in critical thinking skills. The evaluation results demonstrated that the practicum module was valid, practical, and effective in enhancing students' critical thinking skills. The findings from this stage were used as a basis for refining the module and ensuring its feasibility for wider application.

Table 4. Summary of ASIE Development Stages

ASIE Stage	Main Activities	Output
Analyse	Identifying learning needs, analyzing student characteristics, learning outcomes, and existing practicum limitations	Problem identification and need for PjBL-based practicum module
Design	Formulating learning objectives, designing practicum content and PjBL activities, developing critical thinking assessments	Draft of PjBL-based digestive system practicum module
Implement	Applying the module through pre-test, project-based practicum sessions, and post-test	Practical data on module implementation and student performance
Evaluate	Expert validation, student response analysis, pre-test and post-test comparison	Evidence of validity, practicality, and effectiveness of the module

The third stage is implementation; the implementation is carried out on Biology students in the even semester of the 2023/2024 academic year according to the material on the digestive system. Food material test: carbohydrates & vitamin C using several types of Goroho bananas (*Musa acuminafe*), which are local foods in Minahasa. The results of the implementation process are used to see how effective the practicum guidance module is in improving students' critical thinking skills. The design used in the implementation stage in the development of this practicum is one person pretest post-test.

At the final stage of ASIE is evaluation. This stage is carried out after the implementation process in the classroom, and data has been obtained. This stage is carried out to determine the achievement of learning objectives. Evaluation includes a pretest and a post-test. The results of this stage can be a benchmark for the practicum guidance module that was developed and has been declared valid. Validation of the practicum guidance module includes material experts and field practitioners. The criteria for material experts and field practitioners are Biology lecturers and experts in material and learning design. The assessment criteria for the validation test by material experts consist of aspects of the format of the practicum guidance module, attractiveness, shape, letters, and spacing. Validation of material experts is carried out by validators who are experts in the material. Test food ingredients: carbohydrates & vitamin C using several types of Goroho bananas (*Musa acuminafe*).

The collected data will be analysed using qualitative and quantitative analysis methods. (a) Qualitative Analysis. In this analysis technique, qualitative descriptive statistics are used to describe data containing criticisms and suggestions obtained from questionnaires given to construction experts, material

experts, lecturers, peer reviewers, and students. (b) Quantitative Analysis. For quantitative analysis, data obtained from validation results by construction experts, material experts, teachers, and peer reviewers will be expressed in the form of scores with three categories: (3) good, (2) less, and (1) not good. Meanwhile, data from students regarding responses to the quality of the practicum guidance module will be grouped into five categories, namely very good (5), good (4), fairly good (3), not good (2), and very less (1) (Masing & Aminatun, 2022).

FINDING AND DISCUSSION

This development research produces a product in the form of a practical guide module for testing carbohydrate and vitamin C food materials. The analysis stage indicated that students faced difficulties in connecting theoretical concepts with empirical findings during practicum activities and showed limited critical thinking skills. These findings highlighted the need for a structured practicum module that integrates project-based learning (PjBL) to promote active learning and higher-order thinking.

The design stage shows that this practical module design consists of a cover, foreword, table of contents, learning outcomes, theoretical basis, practical objectives, work procedures (tools and materials, practical work methods, worksheets), glossary, and bibliography. The following is a partial display of the developed practical module, which is shown in Figure 1.

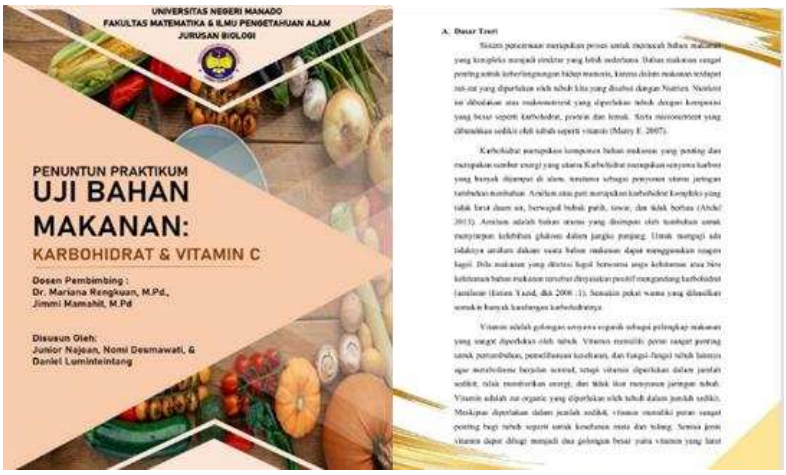

Figure 1. Food Testing Practicum Module: Carbohydrate and Vitamin C

The results of the development of the practical module were first validated by subject matter experts, with an average score of 96.166%, categorized as highly valid. The highly valid module was then pilot tested to determine its effectiveness on students' critical thinking skills. The results of the module validation test can be seen in Table 5. The next step was to validate the developed practical module with media experts. The validation results showed an average score of 95.6%, categorized as highly valid, allowing the module to be used in the trial phase. The validation results are shown in Table 6.

Table 5. Material Expert Validation Result

No	Aspect	Average Score (%)	Category
1	Alignment of the Module with the Material	98	Very valid
2	Agreement of the Material with the Objectives	98	Very valid
3	Clarity of the Theoretical Basis	96	Very valid
4	Clarity of the Practicum Tools and Materials	95	Very valid
5	Clarity of the Practicum Procedures	95	Very valid
6	Language	95	Very valid

No	Aspect	Average Score (%)	Category
	Average Score	96,166%	Very valid

Table 6. Media Expert Validation Result

No	Aspect	Average Score (%)	Category
1	Design	95	Very valid
2	Readability	96	Very valid
3	Efficiency	95	Very valid
4	Layout	97	Very valid
5	Attractiveness	95	Very valid
	Average Score	95,6	Very Valid

To observe whether there was an improvement in students' critical thinking skills, students were asked to complete a pre-test before the lab and a post-test afterward. The results of the students' pre-test and post-test are shown in Table 7. After testing the effectiveness of the PjBL model on critical thinking skills, the next step was to calculate the average student response to the practical module, which can be seen in Table 8.

Table 7. Pretest and Posttest Results of Critical Thinking Skills

No	Indicator	Pre-test score (%)	Category	Post-test Score (%)	Category
1	Observing	55.80	Enough	84,87	Very good
2	Formulating the problem	42.92	Enough	80,95	Very good
3	Formulating a hypothesis	30.78	Enough	86,13	Very good
4	Identifying variables	53.32	Enough	82,39	Very good
5	Communicating data	60.13	Enough	88,76	Very good
6	Concluding	55.12	Enough	90,00	Very good
	Average Score	49.67 %	Cukup	Enough	Very good

Table 8. Students' Response Results to the Module

No	Aspect	Average Score	Category
1	Module Components	90.52	Very Practical
2	Language	83.97	Practical
3	Presentation	93.38	Very Practical
4	Display	91.76	Very Practical
5	Module Use	95.74	Very Practical
	Average Score	91.07%	Very Practical

Practicum guidance module of Testing local food ingredients of the Minahasa community in this case using Goroho banana (*Musa acuminafe*) to determine the content of Carbohydrates and Vitamin C based on the results of the analysis that has been carried out states that the developed practical guidance module is very valid, practical, effective and easy to understand. The validity criteria are in accordance with the components that underline the module and all components of the developed module. The module produced in the development of this practicum guidance is declared valid if the assessment of material experts and field practitioners states that the developed module is based on a theoretical basis.

The validity of a teaching material is inseparable from its practicality and effectiveness. Without continuity between the three criteria, it is impossible for a module to be said to be of quality. The practicality of a development module is determined by a satisfaction questionnaire distributed to students. A module is declared practical if, during field implementation, the validator states that the resulting module can be used (Wulandari et al., 2022). The characteristics of the effectiveness of the resulting development product are the consistency of the design, objectives with the learning experience and learning

achievements achieved by students. The product resulting from this development research is a practical guidance module "food material test: carbohydrates & vitamin C in Minahasa local food" on the human digestive system material. Based on the results of the validity test and effectiveness test as well as seen from student responses to the practical guidance module, it is considered feasible and practical to be used in schools to improve students' critical thinking skills. The results of the validity test of the practical guidance module according to material experts show that the practical guidance module is very practical to use with an average percentage value of 99.375% in the very good category. Findings based on ASIE stages and PjBL implementation can be seen in Table 9.

Table 9. Findings Based on ASIE Stages and PjBL Implementation

ASIE Stage	PjBL Stage in Practicum Module	Student Activities (Based on Module)	Observed Findings	Critical Thinking Indicators
Analyse	-	Identifying learning difficulties and the absence of practicum modules integrating local food and PjBL	Students experienced difficulties connecting digestive system concepts with practicum activities and showed limited critical thinking skills	Problem awareness, initial clarification
Design	-	Designing a PjBL-based practicum module, worksheets, and assessment instruments	A structured practicum module integrating local food *(Musa acuminafe)* and PjBL stages was successfully developed	Logical organization, planning skills
Implement	Problem Identification	Formulating research questions related to carbohydrate and vitamin C content of Goroho bananas	Students were able to formulate clear and investigable problems	Elementary clarification
	Project Planning	Developing hypotheses, identifying variables, and designing experimental procedures	Improved logical reasoning and experimental planning skills were observed	Basic support, inference
	Project Implementation	Conducting carbohydrate and vitamin C testing using local food materials	Students actively engaged in practicum activities and followed procedures accurately	Analytical and procedural thinking
	Data Analysis & Product Development	Analyzing data, creating tables, graphs, and project reports	Students successfully interpreted data and linked empirical results to digestive system concepts	Advanced clarification
	Presentation & Reflection	Presenting project outcomes and reflecting on learning experiences	Students communicated conclusions based on evidence and reflected on the learning process	Evaluation, strategy, and tactics
Evaluate	-	Conducting expert validation, student response surveys, and pre-test–post-test analysis	The module was categorized as valid, very practical, and effective (N-gain = 0.71)	Evaluation and decision making

From the results of the implementation of the practicum guidance module, seen from the results of the pre-test and post-test of students before and after carrying out the practicum to improve students'

critical thinking skills, it can be clearly seen that there has been an increase in students' critical thinking skills. Before carrying out the practicum, students' critical thinking skills by filling out the pretest questions had an average value of only 49.57% with a sufficient category. Meanwhile, after carrying out the practicum, the students answered the posttest questions and it can be seen in Table 6 that there was an increase from the initial 49.57% to 85.51% (very good category). With N-gain score was 0,71 (very good category). Based on the results of the pretest and posttest, it can be clearly seen that there has been a significant increase in students' critical thinking skills. Which means that the implementation of the practicum developed in this study can improve students' critical thinking skills. After carrying out the practicum and filling out the posttest, students were asked to fill out a satisfaction sheet. Based on the satisfaction sheet, it is known that students like and are interested in the practicum guidance module with a percentage of 91.074% with a very practical category. In its implementation, the researcher also observed that students seemed interested and actively involved in this practicum. This category indicates that students consider the module very practical and useful in their learning process.

This data is in line with the PjBL-based biology practicum module in improving students' critical thinking skills developed by Tampubolon & Sipahutar (2024). Where this module was tested valid and categorized as "very feasible" at 91.6% by material experts, learning experts, and layout experts. Students gave very good responses to this module at 87.77% with a very feasible category. This high level of satisfaction reflects that the practicum module is not only effective in improving critical thinking skills, but also in creating a positive learning experience for students. During the practicum implementation, researchers noted that students appeared enthusiastic and actively involved in the practicum activities. This active involvement is one of the main principles of PjBL, where students are encouraged to participate directly in the learning process. When students are actively involved, they are more likely to develop critical thinking skills, because they must analyze information, make decisions, and solve problems that arise during the practicum.

PjBL is effective in fostering students' critical thinking skills because its learning structure requires students to actively engage in higher-order cognitive processes throughout the learning cycle. PjBL begins with authentic and contextual problems that encourage students to analyze situations, identify core issues, and formulate investigable questions. This initial phase trains students to perform elementary clarification, a fundamental component of critical thinking, as students must distinguish relevant information from irrelevant data before proceeding with the project (Markula & Aksela, 2022). Furthermore, during the project planning stage, students are required to design investigation procedures, formulate hypotheses, and determine variables. These activities demand logical reasoning and inference, as students must predict outcomes based on scientific concepts and prior knowledge. Such processes strengthen students' ability to justify decisions and evaluate alternative solutions, which are central elements of critical thinking (Ospankulova et al., 2025).

The implementation stage of PjBL places students in the role of active investigators, where they collect, analyze, and interpret empirical data. This stage facilitates the integration of theoretical knowledge with real-world evidence, enabling students to evaluate the validity of data and draw conclusions based on evidence rather than assumptions. Research has shown that inquiry-driven and project-oriented learning environments significantly enhance students' analytical and evidence-based reasoning skills (Chaijum & Hiranyachattada, 2020; Amaral & Fregni, 2021). In addition, the data analysis and product development stages require students to synthesize information, interpret findings, and construct coherent arguments supported by data. These activities promote advanced clarification and evaluative thinking, as

students must connect empirical results with conceptual frameworks and assess the implications of their findings (Chang & Yen, 2021; Huang et al., 2023).

The final stages of presentation and reflection further strengthen critical thinking by encouraging students to communicate their conclusions, defend their arguments, and reflect on the learning process. Reflection activities enhance metacognitive awareness, enabling students to evaluate their own reasoning strategies and learning outcomes. This reflective dimension is a key factor in sustaining long-term critical thinking development (Wu, 2024; Kong & Hou, 2025). Overall, PjBL fosters critical thinking because it is grounded in authentic problems, emphasizes inquiry and decision-making, integrates theory with empirical evidence, and provides structured opportunities for evaluation and reflection. These characteristics align closely with the core dimensions of critical thinking, making PjBL an effective instructional approach for developing higher-order thinking skills in science education.

The data presented shows a significant relationship between PjBL and the improvement of students' critical thinking skills through the use of the practicum module. In the educational context, PjBL is an approach that focuses on active learning, where students engage in real-life projects that encourage them to think critically, solve problems, and collaborate with their peers. Furthermore, the results of a study by Hikamah et al. (2025) showed that the PjBL model had a partial effect on the dimensions of cooperation, critical thinking, and creativity. Therefore, projects that focus on local wisdom have proven to be an effective strategy to support the development of Pancasila student character profiles and efforts to conserve natural resources. Integrating local wisdom into the learning process can be an innovative approach to supporting the sustainability of natural resources while forming students with integrity in accordance with Pancasila values.

These results may be due to the improvement and development of students' critical thinking skills through the implementation of project-based learning strategies. Fundamentally, this approach is an inquiry-based method in which students function as researchers gaining experience, while teachers act as supervisors and instructors. This aligns with research findings in Malaysia that PjBL can improve residual critical thinking skills compared to conventional learning. This is because conventional teaching methods are considered less effective in developing students' critical thinking skills (Alawi & Soh, 2019). The learning context is developed through real-life questions and problems encountered in everyday life Pramasdyahsari et al. (2023), which provides a more meaningful learning experience. Rehman et al. (2024) added that each stage of the project can enhance students' abilities and stimulate their thinking. Furthermore, inquiry also plays a role in gathering information from various sources in traditional methods, as well as helping them find solutions to problems and improve their skills in constructing explanations. Inquiry also supports students in feeling freer and more responsible in making informed decisions. All stages of project-based learning contribute to the development of critical thinking skills, starting with selecting a project that aligns with students' interests and needs (Issa & Khataibeh, 2021). Project-based learning, which begins with students' prior knowledge and establishes and formulates questions, allows students to broaden their understanding and thinking about the activities developed in this strategy. Furthermore, this method fosters skills in recognizing assumptions and evaluating arguments through classroom discussions of the various project stages and the steps for collecting and analyzing data, culminating in the evaluation and presentation of student findings (Wiyono et al., 2025). In this way, students can connect their existing knowledge with new knowledge, thus achieving a deeper understanding. Students are given the opportunity to construct knowledge independently and determine what they want to learn and how to learn it. The PjBL model has stages that encourage students to develop knowledge independently and actively participate not only in class but also outside of class in

finding solutions to given problems (Issa & Khataibeh, 2021). PjBL is an educational curriculum that supports students' independent learning and helps improve their academic achievement by utilizing their existing knowledge to explore and discover alternatives (Leasa et al., 2023).

The use of this biology practicum module is also more effective in improving students' critical thinking skills in studying animal development courses on the topic of cell determination and differentiation and endoderm derivatives: the digestive tract and glands. Conversely, the critical thinking skills of the experimental class using the project-based module were higher than those of the control class (Khafah & Suprapto, 2023). Thus, the development of an effective project-based module can foster students' critical thinking skills. These skills are essential and needed for problem-solving. Critical thinking skills direct individuals to solve problems logically and accurately by evaluating evidence, assumptions, logic, and language underlying others' thinking to make decisions based on what should be believed and done with a sound knowledge base (Fitriani et al., 2020). Critical thinking skills can be developed/improved through learning activities that utilize learning methods or strategies. One collaboration that can improve students' critical thinking skills is by using learning strategies with the practicum method. The practicum guide aims to facilitate students in carrying out practicums.

The development of practicum instructions is to improve students' critical thinking skills. The development of the practicum guide is categorized as feasible and therefore effective in improving students' critical thinking skills. In the context of the (*Musa acuminafe*) Local Food Nutrition Test, the indicators of critical thinking skills applied include formulating problems, collecting data, providing valid reasons, and conducting evaluations or reflections. This module is also designed by considering contextual problems faced daily and is equipped with questions that encourage critical thinking. In addition, students are actively involved in the investigation process (Yücel & Usluel, 2016). However, this module has several shortcomings that need to be considered for future improvements. One weakness identified is that the implementation of this module takes longer than planned. To overcome this obstacle, the sequence of topics is adjusted to strengthen the relationship between the topics discussed. In this case, the discussion is about the context of the (*Musa acuminafe*) local food nutrition test. Thus, this adjustment is expected to improve the effectiveness of learning and students' understanding of the material taught.

The novelty of this study becomes apparent when compared with existing research. While many studies have implemented PjBL as an instructional model, this research goes beyond methodological application by producing a contextualized practicum guidance module that integrates local Minahasan food resources as the central project substance. Unlike previous practicum modules that rely on standard laboratory materials, this module utilizes Goroho banana as a real and meaningful learning resource. This positioning of local wisdom as the core of the learning project represents a significant contribution that has rarely been explored in prior PjBL-based biology education studies. The added value of this module lies in its dual contribution: pedagogically, it enhances students' critical thinking skills through structured PjBL-based practicum activities; contextually, it promotes awareness and utilization of local natural resources, supporting sustainable and culturally responsive education. By connecting scientific inquiry with students' real environment, the module creates meaningful learning experiences that extend beyond cognitive gains and foster responsible attitudes toward local resource conservation. Despite these strengths, the study also identifies limitations, particularly the longer time required for implementation. To address this issue, adjustments in topic sequencing and tighter integration among project stages are recommended. These improvements are expected to enhance efficiency without reducing the depth of inquiry and critical thinking development offered by the module.

CONCLUSION

This study developed a PjBL-based biology practicum module by utilizing the local food resource Goroho banana (*Musa acuminafe*) and examined its effectiveness in enhancing students' critical thinking skills. Based on the development process using the ASIE model (analyse, design, implement, and evaluate), the resulting practicum module met the criteria of being highly valid, highly practical, and effective. Validation by subject-matter and media experts indicated a very high level of feasibility, demonstrating that the module was designed in accordance with theoretical foundations, learning objectives, and the characteristics of biology practicum activities. The implementation of the PjBL-based practicum module showed a significant improvement in students' critical thinking skills, as reflected in the increase in average pre-test to post-test scores and the N-gain values, which fell within the high category. All critical thinking indicators—including problem formulation, hypothesis development, variable identification, data analysis, and evidence-based conclusion drawing—demonstrated consistent improvement. Moreover, students' responses to the module were categorized as highly practical, indicating that the module was easy to use, engaging, and capable of supporting active student participation in practicum activities. Therefore, it can be concluded that the development of a PjBL-based biology practicum module using the local food resource Goroho banana is effective in empowering students' critical thinking skills, while also bridging the connection between theoretical concepts of the digestive system and real-world contexts within the local environment.

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