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Development of a Biology Learning Module on the Mangrove Ecosystem Subtopic Based on Project-Based Learning (PjBL) at SMAN 1 Batauga

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Abstract
Curriculum change has become inevitable. Moreover, the very rapid development of science and technology no longer allows the education sector to remain with the existing curriculum, namely the 2013 Curriculum, for an extended period. The implementation of the Merdeka Curriculum must take into account the readiness of educational institutions. Teachers must also prepare themselves for the implementation of the Merdeka Curriculum. Teaching resources available on the Merdeka Mengajar Platform (PMM) are still limited, particularly project-based learning modules. Based on direct observations and questionnaires administered to Grade 10 biology teachers at SMAN 1 Batauga, South Buton, Southeast Sulawesi, it was found that teaching materials—especially project-based learning modules—represent one of the shortcomings in biology learning. The material selected for the development of the biology learning module was ecosystems, as it is well suited to the Project-Based Learning (PjBL) model. This research and development study aim to produce a biology learning module on ecosystem material, specifically the mangrove ecosystem subtopic, based on Project-Based Learning (PjBL) at SMAN 1 Batauga. The results of the research and development of the mangrove ecosystem learning module using the ADDIE model were determined based on validity and practicality tests. The validity test results showed a score of 82%, indicating that the module is feasible for use as teaching material. The practicality test based on teacher questionnaires showed a score of 91%, while the student questionnaire results yielded a score of 84.13%, both of which fall into the very practical category. The results of the research and development of the mangrove ecosystem learning module using the ADDIE model were determined based on validity and practicality tests. The validity test results showed a score of 82%, indicating that the module is feasible for use as teaching material. The practicality test based on teacher questionnaires showed a score of 91%, while the student questionnaire results yielded a score of 84.13%, both of which fall into the very practical category. The implementation results based on practicality tests through teacher and student questionnaires indicate that the learning module on the mangrove ecosystem subtopic is categorized as very practical.

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1. Introduction

The curriculum (Suryaman, 2020) [23] is the "soul" of education that must be evaluated in an innovative, dynamic, and periodic manner in accordance with the development of the times and advances in science and technology, as well as the competencies required by society and graduate users. Curriculum change has become inevitable. In fact, the very rapid development of science and technology no longer allows the education sector to remain too long with the existing curriculum, namely the 2013 Curriculum. The implementation of the Merdeka Curriculum (Nugraha, 2022) [15] must take into account the readiness of educational units. Teachers must also prepare themselves for the implementation of the Merdeka Curriculum. The Ministry of Education, Culture, Research, and Technology has developed the Merdeka Mengajar Platform (PMM), which serves as a driving medium for teachers in realizing the Pancasila Student Profile.

The features of PMM include Learning, Teaching, and Creating, which provide various references for teachers to develop teaching practices that are aligned with and consistent with the Merdeka Curriculum.

PMM can be used by teachers to support their professional development and competency enhancement, as well as to access references for various teaching resources of the Merdeka Curriculum. However, some teaching resources are still insufficiently available, particularly project-based learning modules.

Based on direct observations and questionnaires (interviews) with Grade 10 biology teachers at SMAN 1 Batauga, South Buton, Southeast Sulawesi, it was found that teaching materials—particularly project-based learning modules—constitute one of the shortcomings in the learning process, especially in biology subjects. In addition, teachers require project-based learning materials specifically for mangrove ecosystem topics to help achieve learning objectives more effectively. This need is supported by the school's location near coastal areas, which facilitates the implementation of project-based learning. Therefore, it is necessary to develop teaching materials to support and assist biology teachers in delivering learning content in accordance with the Learning Objective Flow (ATP) to ensure that the intended learning objectives are well achieved.

The preparation of teaching materials should include activities that stimulate students to think by developing scientific skills in problem solving. Good teaching materials for students are those that facilitate understanding of the intended concepts of the subject matter (Budiarso, 2016). One appropriate type of teaching material to use at present is a learning module. The development of learning modules also aims to increase students' learning motivation so that they can understand concepts through modules that are engaging, concise, and practical.

The material selected for the development of biology learning modules is ecosystems, as it is one of the topics that aligns well with the Project-Based Learning (PjBL) model. The use of the Project-Based Learning model is expected to create conditions in which individual success is influenced by group success. According to Maisyarah and Lena (2023) [12], the Project-Based Learning (PjBL) model is able to help students understand concepts that are considered difficult and provide satisfaction for both lower- and higher-achieving student groups through cohesion and collaboration, thereby achieving optimal learning outcomes in the studied material. Ecosystem material has also been studied at the junior high school level; therefore, at the secondary education level it can be continued and further developed. The conservation of mangrove ecosystems was selected as the final project title because it is relevant to the preservation of coastal ecosystems, particularly in the South Buton region, which is located in coastal areas.

Indonesia has a vast coastal area that requires serious attention, especially since coastal abrasion frequently occurs in South Buton. Coastal abrasion occurs partly due to the absence of natural barriers in coastal areas, such as mangroves.

According to Utina *et al*. (2018) [25], mangrove forests, seagrass beds, and coral reefs are marine and coastal resources. These coastal ecosystems are interconnected with one another, as well as with human behavior and activities within them. Mangrove ecosystems, for example, serve as spawning grounds for fish and shrimp, in addition to acting as sediment traps that protect coral reef ecosystems and seagrass beds.

Coastal areas are highly vulnerable to environmental degradation, such as pollution, habitat destruction, overexploitation of natural resources, coastal abrasion, conversion of protected areas into development zones, and other natural disasters. One negative impact of coastal area development that leads to environmental change is erosion, which causes shoreline changes. Coastal abrasion may occur naturally due to wave action and human activities, such as port construction, industrial development, and the expansion of aquaculture ponds that force the clearing of mangrove forests (Fajrin *et al*., 2016) [7].

Based on the research reported by Hartini (2016) [8], there are 21 plant species found in the mangrove forest of Kakenauwe, Buton Island. Twelve of these species are classified as rare plants with a conservation status of Least Concern. The dominant mangrove species in the area include Sonneratia ovata, Rhizophora mucronata, Ceriops tagal, Bruguiera gymnorrhiza, and Avicennia marina. Therefore, these species need to be conserved, socialized, and cultivated to ensure their sustainability.

According to Putro (2022), teaching materials are materials used by teachers and students in the learning process. Teaching materials assist teachers by providing ready-to-use content to be delivered to students. They also facilitate student learning and can be used both inside and outside the school environment. Students can learn individually or in groups according to their needs using teaching materials. Teaching materials, as stated by Magdalena *et al*. (2020) [11], are an important component in the implementation of education. Through teaching materials, teachers can conduct learning activities more easily, and students are better supported and find learning easier. Teaching materials can be developed in various forms according to the needs and characteristics of the subject matter to be presented.

The function of teaching materials (Nurdyansyah, 2018) [16] is to serve as motivation in the teaching and learning process carried out by teachers through contextual learning content, enabling students to perform learning tasks optimally. More specifically, the functions of teaching materials are as follows:

1. To serve as a guideline for teachers in directing all activities in the learning process, as well as representing the substance of competencies that should be taught and practiced by students.
2. To serve as a guideline for students in directing all activities in the learning process, as well as representing the substance of competencies that should be mastered by students.
3. To function as a tool for evaluating the achievement and mastery of learning outcomes.
4. To assist teachers in the teaching and learning process.
5. To assist students in the learning process.
6. To function as learning resources to achieve lesson objectives or learning outcomes.
7. To help create a conducive learning environment and atmosphere.

The benefits of teaching materials for students include the following:

1. Learning experiences become more engaging and interesting.
2. Providing opportunities for independent learning and

reducing dependence on the presence of teachers.
3. Facilitating the acquisition and mastery of the competencies that students are required to achieve.

Teaching materials vary widely in form, including both printed and non-printed materials. Printed teaching materials include handouts, modules, textbooks, and worksheets such as LKS (Student Worksheets) or LKPD (Learner Worksheets). Non-printed teaching materials include audio, audiovisual, and interactive multimedia (Kelana, 2019). According to Asep Sunantri, a module is a teaching material that is systematically and attractively designed, encompassing content, methods, and evaluation, and can be used independently to achieve predetermined indicators (Asep Sunantri & Agus Suyatna, 2021) [3]. Modules are essential as learning media that help students understand subject matter and serve as guides for teachers in delivering instructional content. In addition, the availability of modules in classroom learning activities can stimulate both students and teachers to foster enthusiasm for learning and teaching.

Pusdiklat Perpusnas defines a module as a unified set of learning materials that can be studied independently by learners. It contains clear components and instructions that allow learners to follow the learning process sequentially without the intervention of an instructor. Meanwhile, according to the online Indonesian Dictionary (KBBI), a module is a teaching–learning program that can be studied by students with minimal assistance from a supervising teacher, including clear planning of learning objectives, provision of learning materials, required tools, and assessment instruments to measure students' success in completing the learning process.

The use of modules as learning facilities or resources has been widely applied and developed with the objectives of: (a) shortening the time required by students to master learning tasks; and (b) providing students with sufficient time, within reasonable limits, to implement structured and systematic education (S. Sirate & Ramadhana, 2017) [19].

Maulida argues that teachers should develop learning modules optimally; however, in reality, many teachers do not fully understand the techniques for designing and developing learning modules, particularly within the Merdeka Curriculum. Learning processes that do not involve well-planned modules are likely to result in unsystematic delivery of instructional materials to students, leading to an imbalance in learning activities between teachers and students. Consequently, either only the teacher is active or vice versa, and the learning process appears less engaging because teachers do not adequately prepare their learning modules (Maulida, 2022) [14].

An ecosystem is a community of organisms interacting with one another along with the environment in which they live, collectively interacting with their surroundings; examples include lakes, forests, grasslands, and tundra. Such systems encompass all abiotic components, including mineral ions, organic compounds, and climatic conditions (temperature, rainfall, and other physical factors). Biotic components typically include representatives of various trophic levels: primary producers (autotrophs, mainly green plants), macroconsumers (heterotrophs, mainly animals) that consume other organisms or organic matter, and microconsumers (saprotrophs, mainly bacteria and fungi) that decompose complex organic compounds when organisms die and release nutrients back into the environment for reuse by primary producers (Abercrombie, 1993) [1]. According to Soemarwoto, an ecosystem is an ecological system in which reciprocal interactions occur among its constituent components. These components include both biotic and abiotic elements. Organisms that form a community and ecosystem constitute an integrated unit, creating a complex and interconnected web of life (Ramadhan *et al*., 2022) [17].

Living organisms and their environment, both biotic and abiotic, are involved in complex reciprocal relationships. A balanced ecosystem can occur when reciprocal interactions exist among ecosystem components. Initially, producers, herbivores, and carnivores occupy specific positions, with plants as producers being the most abundant. If environmental changes occur, organisms may not immediately be affected; however, if population sizes become uncontrolled, they may endanger other organisms (Sitanggang & Yulistiana, 2015) [21].

In his book, Campbell (2004) states that the success of an organism in surviving and reproducing reflects its overall tolerance to the full range of environmental variables it encounters. In many cases, the ability to tolerate one factor may depend on another. For example, many aquatic ectothermic organisms can survive in environments with low oxygen levels at low temperatures, but not at high temperatures when their metabolic rates are also high.

In mangrove ecosystems, the food chain that occurs is also a detritus food chain. The primary source of detritus comes from decomposed mangrove leaves and branches. Fallen leaves and some algae are consumed by various bacteria and fungi. These bacteria and fungi are then consumed by protozoa and other invertebrates, which in turn are eaten by higher-level carnivores (Romimohtarto, 2009) [18].

One learning model that is suitable for biology instruction is Project-Based Learning (PjBL). Project-Based Learning is defined as a learning process that directly involves students in producing a project. Essentially, this learning model emphasizes the development of problem-solving skills through project work that results in tangible outcomes. In its implementation, this model provides students with broad opportunities to make decisions in selecting topics, conducting research, and completing specific projects (Sari & Angreni, 2018) [20]. The steps of the Project-Based Learning model are described by Anggraini and Wulandari (2020) [2] as follows:

Determining the Project

The teacher presents the topic and problem orientation in the learning process, followed by activities in which students pose fundamental questions about how to solve the problem. Subsequently, students identify appropriate steps to address the problem.

Planning the Steps for Project Completion

The teacher groups students according to the procedures for project development. Students then engage in problem-solving through discussion activities.

Developing a Project Implementation Schedule

The teacher and students collaboratively determine the steps and timeline for completing the project. Students then organize and prepare the steps and schedule for project implementation.

Completing the Project with Teacher Facilitation and Monitoring

The teacher monitors students' engagement during project completion as well as the implementation of problem-solving activities. Students carry out the project according to the established schedule.

Preparing Reports and Presenting/Publishing Project Results

The teacher conducts discussions to monitor students' progress. The outcomes of these discussions are compiled into reports to be presented or shared with others.

Evaluating the Project and Project Outcomes

The teacher guides the project presentation process, followed by reflection and the formulation of general conclusions based on observation sheets completed by the educator.

The Project-Based Learning (PjBL) model encourages students to become more active and creative, increases students' self-confidence, and enhances their ability to work independently in designing and completing projects (Maisyarah & Lena, 2023) [12]. Consistent with the findings of Suaidiah *et al*. (2024) [22], learning through the implementation of the Project-Based Learning (PjBL) model is able to improve students' collaboration skills and learning outcomes in ecosystem topics. This is because the Project-Based Learning (PjBL) model requires students to actively collaborate in completing assigned projects, thereby gradually enhancing collaboration and critical thinking skills, which in turn leads to improved learning outcomes.

According to Wahyuningtyas (2019) [27], the Project-Based Learning (PjBL) model is highly effective in achieving meaningful learning activities in biology subjects. Biology learning using the Project-Based Learning (PjBL) model is designed to address complex problems that require students to conduct investigations to understand them, emphasize extended learning activities, and involve multidisciplinary, product-oriented tasks.

2. Method

2.1. Types of Research

This study employs a development research approach, also known as Research and Development (R&D). The development model used in developing this module is ADDIE. This development model has advantages in its systematic implementation stage, as each phase includes evaluation, thereby minimizing errors in producing a high-quality and feasible product. The ADDIE development model consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Cahyadi, 2019) [4].

The analysis stage involves identifying problems or needs to obtain information regarding learner characteristics and the teaching materials to be developed. The results of this analysis determine the most appropriate learning resources to be provided to students. This needs analysis stage was conducted through direct observation and teacher questionnaires at SMAN 1 Batauga, South Buton, Southeast Sulawesi.

The design stage is the initial phase in planning the product to be developed, namely a learning module. The module framework consists of an introduction, learning activities, and practice questions.

The development stage involves producing a product based on learning needs and objectives, as well as developing validation instruments (Malik, 2021) [13]. This stage was carried out by realizing the learning module design that had previously been prepared during the design stage. After the learning module was completed, the implementation stage was conducted with expert validators.

The implementation stage involved conducting a limited trial with teachers and students to assess the practicality of the module. The results of the implementation were then evaluated. The evaluation stage involves analyzing the developed learning module to determine its practicality.

Teacher and student evaluations were conducted using questionnaires administered to students to obtain assessments of the practicality of the mangrove ecosystem biology learning module. Data obtained from teachers and students were used as the basis for revising the mangrove ecosystem biology learning module.

2.2. Research Subjects and Objects

The subjects of this study were informants who served as samples to obtain information about biology learning in the classroom, particularly on ecosystem topics. The respondents in this study consisted of two biology teachers and fifteen Grade 10 students. The object of the study was the development of teaching materials in the form of a Project-Based Learning (PjBL)–based biology learning module on the subtopic of mangrove ecosystems, based on data obtained from respondents regarding the background of the problems at SMAN 1 Batauga.

2.4. Data analysis technique

The data analysis technique was conducted through expert validation tests and practicality assessments by teachers and students. Product validation was carried out to ensure that the developed module met feasibility requirements. The data used consisted of scores obtained from subject matter experts, media experts, and language experts. The scores from the questionnaires were used to assess the feasibility of the developed module. The feasibility of the product was determined by comparing the validation results from the experts with predetermined criteria, as presented in Table 1.

Table 1: Interpretation of the Feasibility of Teaching Materials

No.	Feasibility Criteria	Feasibility Criteria
1.	86% – 100%	Very Feasible
2.	76% – 85%	Feasible
3.	56% - 75%	Less Feasible
4.	≤ 55%	Not Feasible

Source: Sugiyono (2008) in (Tia, 2020).

The data analysis technique employed a Likert scale. Score interpretation was obtained by comparing the item scores provided by experts with the highest possible score and then multiplying the result by 100%.

$$Iterpretasi\ Skor = \frac{Skor\ item}{Skor\ Tertinggi}\ x\ 100\%$$

After obtaining scores for each assessment aspect from the subject matter experts, media experts, and language experts, the average score was calculated using the following formula:

$$Skor\ Rata - rata\ (\bar{x}) = \frac{Jumlah\ total\ skor\ (\Sigma x)}{Jumlah\ Pernyataan}$$

The data collection techniques used in this study to obtain data in accordance with the research objectives were as follows:

1. Interviews, which were conducted with teachers and other relevant sources within the senior high school environment. The interview technique employed in this study was unstructured interviews. In line with this interview format, the researcher was not strictly bound to an interview guideline.
2. Questionnaires, which were used to measure the effectiveness of the product. The questionnaire instrument was designed to evaluate the quality of the module to ensure that the product was suitable for use.

The results of the interviews and questionnaires were used to revise the product being developed. The module assessment questionnaire for experts consisted of material feasibility, media feasibility, and language feasibility. The quality indicators for module development included material relevance, content depth, and language use. The learning module design indicators included layout and typography or language, completeness of presentation, completeness of layout elements, and the integration of content and images. The validator criteria are presented in Table 2.

Table 2: Validator Criteria

No.	Type of Validation	Validator Criteria	Σ
1.	Subject Matter and Media Expert	a. Master's degree (M.Ed.) in Biology Education b. Senior teacher at SMAN 3 Sidoarjo c. 23 years of teaching experience d. Experience in developing teaching materials at school	1
2.	Language Expert	a. Master's degree (M.Ed.) in Indonesian Language and Literature Education b. Lecturer at Universitas Sembilanbelas November Kolaka c. 10 years of teaching experience d. Author of journal articles on the implementation of Project-Based Learning models	1

After the validation test was conducted, it was followed by a practicality test. The practicality test was obtained through response questionnaires administered to students and teachers. The percentage scores of the respondents' indicator statements were adjusted to the practicality criteria, referring to Sugiyono (2017) as cited in Uyuni (2024).

Table 3: Practicality Criteria

Skor	Criteria
100 ≥ X > 75	Very Practical
75 ≥ X > 50	Practical
50 ≥ X > 25	Fair
25 ≥ X	Less Practical

3. Results and Discussion

The ADDIE stages in the development of the biology learning module on the subtopic of mangrove ecosystems are explained as follows.

A. Analysis

The first stage is needs analysis. Based on the results of interviews and questionnaires administered to Grade 10 biology teachers, it was found that one of the shortcomings at SMAN 1 Batauga is the absence of Merdeka Curriculum–based learning modules, particularly those addressing coastal ecosystem topics such as mangrove ecosystem learning modules using a Project-Based Learning model. In addition, the textbooks available to students do not cover ecosystem material in depth; therefore, teachers need to provide alternative learning resources.

B. Design

Based on the results of the analysis, the design stage was subsequently conducted. At this stage, the learning module was developed according to the predetermined framework.

C. Development

Following the design stage, the development stage was carried out. At this stage, the module underwent validation by expert validators, as presented in the table below.

Material and media validation was conducted by Farida Dwi Susanti, S.Pd., M.Pd., while language validation was conducted by Kadirun, S.Pd., M.Pd. After validation, revisions were made based on the validators' suggestions.

Table 4: Results of Subject Matter and Media Expert Validation

No. Statement	Validator Results (%)		
	Topic	Media	Average
1.	100	100	100
2.	60	100	80
3.	80	80	80
4.	60	80	70
5.	60	60	60
6.	100	100	100
7.	80	100	90
8.	80	100	90
9.	80	100	90
10.	60	60	60
Rata-rata	76	88	82

Based on the table above, it can be concluded that the validation results from the subject matter and media experts for the developed learning module yielded an average score of 82%, which falls under the feasible criterion for use in learning. Meanwhile, the individual validation results show that the material validation score was 76%, categorized as feasible, and the media validation score was 88%, categorized as very feasible.

Table 5: Results of Language Expert Validation

No. Statement	Language Validator Results (%)
1	100
2	80
3	100
4	100
5	80
6	80
7	100
8	80
9	100
10	100
Average	92

Based on the language expert validation results table, the mangrove ecosystem learning module was rated in the very feasible category with a score of 92%. This indicates that the language used is of very high quality and that the developed module can be used as teaching material.

Evaluation was conducted by obtaining assessments of the mangrove ecosystem learning module from experts. The comments and suggestions were then used to revise the developed learning module. The experts' comments and suggestions are presented in Table 6.

Table 6: Experts' Comments and Suggestions

Expert Validator	Comments/Suggestions	Revisions
Material and Media Expert	1. Please standardize the font type for each sentence/paragraph and content, especially the problem-triggering questions, so that they align with the learning objectives/targets. 2. Align the Learning Objective Flow (ATP) with the learning objectives. 3. Use Learning Outcomes (CP) only for Grade 10. 4. Complete the characteristics of mangroves—such as roots, growth form (habitus), leaves, flowers, and fruits—with examples 5. Images should include their sources and locations 6. Media in the form of video links should specifically relate to mangrove ecosystems 7. Ensure that the projects planned in the module align with the learning objectives. | 1. Font types have been standardized	1. Font types have been standardized. 2. The Learning Objective Flow (ATP) has been aligned. 3. Learning outcomes have been revised. 4. Mangrove characteristics have been completed with examples. 5. Images have been provided with sources 6. Video links have been replaced with those related to mangrove ecosystems 7. Projects have been aligned with the learning objectives.
Language Expert	1. In writing, font usage should be consistent (e.g., page 7)., 2. The use of non-standard words should be avoided (e.g., *projek* on page 5), 3. The layout of titles, subtitles, and bold formatting should be reorganized consistently.	1. Font types have been standardized. 2. The word *projek* has been revised to *proyek* 3. The layout of titles, subtitles, and bold formatting has been reorganized consistently.

5. Conclusion

Based on the results of the research on the development of a mangrove ecosystem learning module using the ADDIE model, it can be concluded that:

1. A biology learning module on the subtopic of mangrove ecosystems based on Project-Based Learning (PjBL) was successfully developed using the ADDIE development stages (Analysis, Design, Development, Implementation, and Evaluation).
2. The implementation results based on practicality tests through teacher and student questionnaires indicate that the mangrove ecosystem learning module falls into the very practical category.

Based on the research findings and discussion, the authors recommend that:

1. Biology teachers at SMAN 1 Batauga or other relevant parties may use the developed mangrove ecosystem learning module as teaching material or a reference, as it has passed validity and practicality tests.
2. Future researchers are encouraged to conduct further trials of the learning module on a larger scale.

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