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Development of Supplementary Teaching Materials for Lower Plant Botany Based on Local Potential of Ferns (Pteridophyta) in Coastal Areas

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Abstract

This study aimed to develop supplementary teaching materials for the Lower Plant Botany course in the form of a contextual resource integrating text, images, tables, and local examples to support independent learning on Pteridophyta based on the ecological potential of the coastal area of Waai Village, Maluku. The study employed a Research and Development approach using the Four-D (4D) model, consisting of define, design, develop, and disseminate stages. Ecological inventory data of coastal ferns served as the foundation of the material content. A total of nineteen fern species were identified and systematically integrated into the teaching materials to support contextual learning. Unlike previous local-potential-based materials, this product was developed from a systematic inventory of coastal fern species, allowing field-based ecological data to be transformed into instructional examples for higher education biology learning. The materials were evaluated through expert validation involving specialists in content, media, and language, as well as a student readability test with biology education undergraduates. The average expert validity score was 79.0%, indicating that the materials were valid with minor revisions, while student readability scores ranged from 92.00% to 95.00%, categorized as very good. Although learning effectiveness was not examined, the findings indicate that teaching materials derived from local ecological inventory data are feasible as contextual supplementary resources in preservice biology teacher education.

Keywords: Pteridophyta; Local potential; Teaching materials; Lower plant botany; Preservice teacher education

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INTRODUCTION

Biology learning in higher education, particularly in biology education programs, requires contextual teaching materials that enable pre-service teachers to develop a deep understanding of biological concepts and relate them to real environmental phenomena (Jeronen et al., 2016). This need becomes more pronounced in courses with high conceptual demands, such as Lower Plant Botany, which requires students to understand the morphological, ecological, and taxonomic characteristics of early vascular plants (Maskour et al., 2019). Previous studies have shown that integrating local and cultural contexts into learning can strengthen the relevance of instructional content and promote more meaningful learning experiences (Batlolona et al., 2026). Accordingly, teaching materials that explicitly connect botanical content with the surrounding environment are essential for preparing prospective biology teachers with adequate ecological and pedagogical literacy (Gutiérrez-García et al., 2024).

This need is particularly evident in the teaching of Pteridophyta, which is often presented in a predominantly textual manner and detached from students' immediate environmental context (Goswami et al., 2016). Such an approach may limit students' ability to internalize fern diversity and understand morphological traits and ecological adaptations through concrete examples from their own environment (Kluge & Kessler, 2007). The problem is further exacerbated by the widespread use of generic teaching materials that insufficiently highlight local biological potential as a learning resource for prospective biology teachers (Miarsyah et al., 2021). As a result, opportunities for contextual and meaningful learning in Lower Plant Botany remain limited, even though the subject matter is closely related to observable ecological phenomena (Jeronen et al., 2016). The abstract nature of Pteridophyta content makes contextual support particularly important in instruction. Preliminary observation revealed that the available teaching materials had not yet been developed on the basis of local ecological potential, while initial student interviews indicated a perceived need for contextual supplementary materials to facilitate understanding.

The use of local context is important in biology learning because it helps students connect abstract concepts with authentic ecological conditions that can be directly recognized in their environment (Hubbard, 2024). Local potential–based biology learning has also been reported to support the development of scientific literacy, critical thinking skills, and students' ability to relate biological concepts to real ecological settings (Purwasih et al., 2025). For preservice biology teachers, contextual teaching materials are particularly important because they not only support content mastery but also model how local environments can be transformed into meaningful instructional resources (Gutiérrez-García et al., 2024). In this regard, local biological potential should be viewed not merely as an illustration, but as a pedagogically relevant foundation for instructional material development (Batlolona et al., 2026).

Several previous studies have demonstrated the pedagogical value of integrating local potential into Pteridophyta learning. The use of local biological objects has been reported to improve the readability of teaching materials for fern-related content (Efendi et al., 2023). Likewise, the integration of locally sourced examples has been shown to increase content relevance and support students' understanding of fern morphology and ecology (Yudhistian & Wulandari, 2024). These findings confirm that local context is pedagogically valuable in botany learning and should be more systematically integrated into instructional design (Sukadari et al., 2023).

However, most previous studies have used local context mainly as illustrative support, such as examples or biological objects, rather than as systematically collected ecological inventory data serving as the principal basis for content development. Consequently, the connection between plant ecological research and structured teaching materials for Lower Plant Botany remains limited (Yusuf, 2023). This gap is especially important because the development of instructional materials based on field inventory data can strengthen both scientific accuracy and contextual relevance in biology learning (Fedesco et al., 2020). Therefore, a stronger integration between ecological evidence and instructional content is needed in the development of Pteridophyta teaching materials (Sukadari et al., 2023).

This need is highly relevant in coastal ecosystems, which provide authentic environmental settings that can enrich the teaching of Pteridophyta. Previous educational studies have shown that environmental themes and place-based contexts can function as meaningful resources for strengthening the connection between scientific content and real-world settings (Freitas et al., 2025). Waai Village, Maluku, was selected as the research site because its coastal area contains relatively well-preserved and heterogeneous habitats that support fern diversity and are therefore suitable for ecological inventory studies. The use of field-based data from such environments allows teaching materials to present concrete examples that enhance students' understanding of morphology, ecology, and taxonomy in relation to actual environmental conditions (Fedesco et al., 2020).

Within Universitas Pattimura, there is currently no formally documented supplementary teaching material that specifically utilizes local coastal fern diversity as the primary content basis for Pteridophyta instruction among preservice biology teachers. The absence of such resources underscores the need for teaching materials that are not only content-relevant, but also contextual and empirically grounded. Previous studies have also shown that authentic, research-based ecological learning can enhance meaningful learning experiences, student motivation, and understanding of scientific practices in higher education (Walkington & Ommering, 2022). In this context, the integration of ecological inventory data into teaching materials represents a strategic effort to connect plant diversity research with biology teaching practices in higher education.

The novelty of this study lies in the development of supplementary teaching materials for Lower Plant Botany based on a systematic ecological inventory of coastal ferns in Waai Village, Maluku, rather than relying only on general local examples or illustrative biological objects. In this study, local ecological potential is positioned not merely as contextual enrichment, but as the primary basis for content development derived from field inventory results. The field inventory documented 19 fern species, and these data were transformed into contextual instructional content for Pteridophyta learning. Through this approach, the study seeks to bridge plant ecological research and biology teaching practices while strengthening contextual learning resources for preservice biology teachers.

Based on these considerations, this study aims to develop supplementary teaching materials for the Lower Plant Botany course focusing on Pteridophyta and grounded in ecological inventory data of ferns from the coastal area of Waai Village, Maluku. The product is designed as a contextual supplementary teaching resource for preservice biology teachers and is evaluated through expert validation and student readability testing. The scope of the study is limited to product development, validity, and readability, and does not include effectiveness testing in classroom implementation. In addition, dissemination in this study is limited, so the contribution of the product is positioned primarily at the level of feasibility as a contextual supplementary teaching resource.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using the Four-D (4D) development model, which consists of define, design, develop, and disseminate stages. The 4D model was selected because it provides a systematic framework for developing educational products through needs analysis, product design, expert validation, and limited dissemination prior to wider implementation. This model has been widely applied in science and biology education research to produce learning materials that are pedagogically feasible and contextually relevant (Alenezi, 2019). In the present study, the 4D model was used to develop supplementary teaching materials for the Lower Plant Botany course, particularly the Pteridophyta topic, based on local ecological inventory data, without conducting experimental testing of learning effectiveness.

Research Setting

The ecological inventory was conducted in the Rumah Pohon tourism area, Waai Village, Maluku, because the area has relatively intact coastal ecosystems and habitat diversity that support the growth of various fern species. The development, validation, and readability testing of the teaching materials were carried out at the Biology Education Study Program, Universitas Pattimura. The product evaluation stage involved expert validators in material, media, and language, as well as undergraduate students of the Biology Education Study Program. This research setting is consistent with the original manuscript, which places the ecological inventory in Waai Village and the product development process within the Biology Education Study Program of Universitas Pattimura.

Product Description

The product developed in this study was a supplementary teaching material for the Lower Plant Botany course focusing on Pteridophyta. The material was prepared in PDF format using word-processing software and Canva to ensure ease of access, flexible distribution, and practical use by students and lecturers. The selection of PDF format was intended to accommodate the need for accessible learning resources amid infrastructural limitations that are still encountered in some parts of Eastern Indonesia.

The content of the supplementary teaching material consisted of a cover page, table of contents, an introductory section on Pteridophyta, a section presenting the local ecological context of Waai Village, and species-based content discussing all fern species identified from the ecological inventory. Each species section presented relevant descriptive information to support students' contextual understanding of fern diversity in Lower Plant Botany. The material was designed as a supplementary resource rather than a full instructional module, with emphasis on contextual enrichment through local ecological data. Representative pages of the developed product should therefore be presented in the revised manuscript to show the cover, content structure, and examples of species-based pages.

Tools and Materials

The tools and materials used in this study included field observation sheets and inventory forms for the identification of ferns, as well as a digital camera to document plant morphology and habitat characteristics. A computer was used for data processing and material development. The supplementary teaching materials were developed using word-processing software and Canva, which were used to prepare the layout, integrate text and visual elements, and improve the visual readability of the material. Relevant references on Lower Plant Botany and teaching material development were used to ensure content accuracy, relevance, and scientific validity.

Development Procedures

The development procedures were systematically conducted using the Four-D (4D) model consisting of define, design, develop, and disseminate stages. In the original manuscript, the define stage includes identification of instructional needs, student characteristics, and Pteridophyta content, as well as ecological inventory activities in Waai Village. The design stage focuses on the initial structure of the supplementary teaching material and the preparation of validation and readability instruments. The develop stage includes expert validation, readability testing, and product revision, while the disseminate stage is limited to sharing the validated product within the academic environment of the Biology Education Study Program. In this study, the 4D model was adapted from Utaminingsih et al. (2024) to accommodate the objectives of developing supplementary teaching materials grounded in local ecological data.

Each stage of the 4D model was implemented in accordance with the characteristics of biology education research and the context of Lower Plant Botany learning. The adaptation emphasizes the integration of ecological inventory data at the define stage, pedagogical design at the design stage, expert validation and readability testing at the develop stage, and limited dissemination without experimental testing at the disseminate stage. The overall development flow of the adapted 4D model applied in this study can be seen in the figure 1.

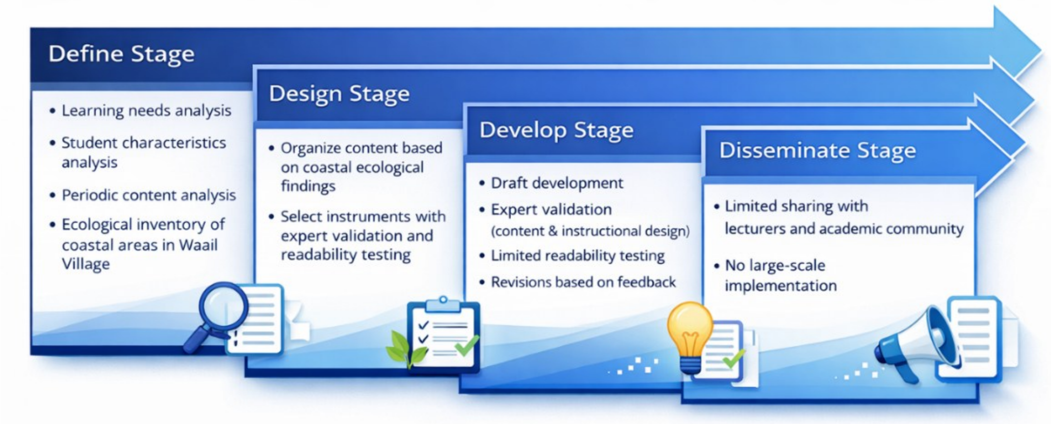

Figure 1. 4D models of research

At the define stage, an analysis of learning needs and student characteristics was conducted to identify the relevance of the Pteridophyta topic in the Lower Plant Botany course. This stage also involved an ecological inventory of coastal ferns in Waai Village to obtain empirical data that would serve as the foundation for the teaching material content. At the design stage, the initial structure of the supplementary teaching material was prepared by organizing the concepts, selecting a contextual format, and developing the expert validation and student readability instruments.

At the develop stage, the initial draft of the product was produced and evaluated through expert validation and student readability testing. Revisions were then made on the basis of validator comments and student responses to improve content accuracy, language clarity, layout, and contextual relevance. At the disseminate stage, the validated product was shared in a limited manner with lecturers and the academic community in the Biology Education Study Program. This stage did not involve large-scale implementation or experimental evaluation of learning outcomes.

Ecological Inventory Procedure

The ecological inventory was conducted in the Rumah Pohon tourism area, Waai Village, Maluku. Fern data were collected through direct field observation using a quadrat-transect method along the access route to the tourism area, with a transect length of approximately 6 km. Observation plots measuring 10 × 10 m were established along the transect, and the distance between plots ranged from 1 to 3 m depending on the presence of ferns in the field. A total of 44 quadrats were observed in one station.

In each plot, the fern species encountered and the number of individuals of each species were recorded and documented photographically. Species identification was carried out based on field documentation and verified using relevant botanical encyclopedias and fern identification references. The inventory data were analyzed descriptively and used as the empirical basis for developing the local species content presented in the supplementary teaching material. As reported in the inventory results, the field data documented 19 fern species with a total of 5664 individuals from 44 quadrats in one station.

Validation and Readability Instruments

The instruments used in this study consisted of expert validation sheets for material, media, and language, each tailored to the characteristics of the teaching materials. All items were scored using a 4 point Likert scale (4 = very good, 3 = good, 2 = fair, 1 = poor) to ensure clear and decisive evaluation. The use of Likert-scale expert validation sheets evaluated by a panel of specialists is a widely accepted procedure in educational instrument development (Moreira-mora & Espinoza-guzmán, 2016). For the aspects assessed in the expert validation sheets, they are summarized in Table 1.

Table 1. Expert Validation Instruments

Validator	Aspects Assessed
Material (Subject Matter Expert)	- Alignment with Course Learning Outcomes (CLOs) and Course Learning Objectives (LOs) - Conceptual accuracy of Pteridophyta - Depth and breadth of content - Accuracy of scientific terminology and classification - Integration of local ecological context (Waai Village)
Media (Instructional Expert)	- Systematic presentation of content - Layout consistency - Integration of text, images, and tables - Visual readability - Support for independent learning
Language (Language Expert)	- Sentence clarity - Grammatical accuracy

Validator	Aspects Assessed
	- Consistency of scientific terminology - Appropriateness of language level for undergraduate students - Overall text readability

The expert validation process involved three validators, each representing a different area of expertise, namely one material expert, one media expert, and one language expert. Each validator assessed the product independently using a validation sheet specific to the corresponding domain. Because each validation aspect was assessed by a single expert, inter-rater agreement was not calculated. Therefore, the validation results should be interpreted as initial expert-based feasibility judgments rather than multi-rater consensus.

Following the completion of expert validation, a student readability assessment was conducted with 20 third-semester undergraduate students enrolled in the Biology Education Study Program, Universitas Pattimura, who were taking the Lower Plant Botany course. Student responses were collected anonymously to reduce potential response bias. The assessment employed a structured questionnaire based on a four-point Likert scale, where responses ranged from 4 (very easy) to 1 (difficult), allowing for a nuanced evaluation of students' perceptions of the teaching materials. The questionnaire was designed to systematically evaluate multiple dimensions critical to learning effectiveness, including the clarity and comprehensibility of textual explanations, understanding of Pteridophyta concepts, appropriateness of language for the target student level, visual readability of figures, tables, and diagrams, relevance of examples to local contexts, and the extent to which the materials supported independent learning. The specific aspects and indicators assessed during the student readability evaluation are presented in detail in Table 2.

Table 2. Readability Instruments (Students)

Aspect Assessed	Purpose
Clarity of text and sentences	To determine whether language and explanations are easy to understand
Comprehension of concepts	To assess understanding of key terms and concepts (Pteridophyta)
Appropriateness of language	To ensure language is suitable for undergraduate biology education students
Visual readability	To evaluate readability of text, tables, images, and diagrams
Relevance and context	To check if examples and local context facilitate understanding
Support for independent learning	To assess whether students can study independently using the materials

Data Analysis

Data were analyzed using descriptive quantitative and qualitative techniques. Expert validation and readability data were analyzed by calculating mean scores across assessment indicators, which were then converted into percentage levels to determine the feasibility of the teaching materials. Percentages were calculated as follows:

$$\text{Validity (\%)} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100\%$$

The resulting percentages were then interpreted according to the validity criteria used in this study, as presented in Table 3. The validity criteria were adapted from Wiyono, Ismet, et al. (2025) and were used as the basis for determining whether the developed teaching material was feasible for instructional use. Qualitative feedback from validators and students was analyzed descriptively and used to improve clarity, structure, language, visual presentation, and contextual relevance of the product. Ecological inventory data were also analyzed descriptively to identify the fern species recorded and to support the preparation of local species-based content in the supplementary teaching material.

Because this study was designed as a feasibility-oriented development study, descriptive validation and readability analysis were considered sufficient to determine whether the product met the minimum academic, pedagogical, linguistic, and contextual criteria for use as a supplementary teaching resource. However, this study did not include inter-rater agreement analysis within the same validation domain, construct validation of the readability instrument, or experimental testing of learning effectiveness. These limitations should therefore be considered in interpreting the findings.

Table 3. Criteria for Validity of Teaching Materials

Validity Percentage (%)	Validation Level
80.01 – 100.00	Very valid
60.01 – 80.00	Valid
40.01 – 60.00	Less valid
20.01 – 40.00	Not valid
0.00 – 20.00	Very invalid

RESULTS AND DISCUSSION

Inventory of Fern Species (Pteridophyta) in the Coastal Area of Waai Village

The primary outcome of this study was the ecological inventory of fern species conducted in the coastal area of Waai Village, Maluku. This inventory served as a comprehensive and systematic empirical foundation for the development of supplementary teaching materials for the Lower Plant Botany course, ensuring that all instructional content was firmly grounded in authentic, locally sourced ecological data. Field observations were meticulously carried out to document each fern species, recording detailed information on taxonomic classification, morphological characteristics, habitat preferences, and relative abundance within the study area. A total of 19 fern species were identified, spanning multiple classes, orders, families, genera, and species, thereby reflecting the rich biodiversity and ecological complexity of the local coastal ecosystem. The diversity of ferns observed highlights the heterogeneity of habitats in Waai Village, encompassing both terrestrial and semi-aquatic environments, which supports a variety of ecological adaptations. This extensive species inventory not only provides valuable biological data but also enables the teaching materials to present concrete, contextually relevant examples that enhance students' understanding of fern morphology, ecology, and taxonomy. The complete results of the fern inventory, including taxonomic classifications and abundance details, are presented in Table 4.

Table 4. Inventory of Fern Species (Pteridophyta) in the Coastal Area of Waai Village

Family	Genus	Species	Number of Individuals
Dryopteridaceae	Nephrolepis	Nephrolepis exaltata	757
Gleicheniaceae	Gleichenia	Gleichenia linearis	2751
Blechnaceae	Blechnopsis	Blechnopsis orientalis	321
Davalliaceae	Davallia	Davallia repens	217
Davalliaceae	Davallia	Davallia fajeensis	3
Lycopodiaceae	Palhinhaea	Palhinhaea cernua	537
Thelypteridaceae	Cyclosorus	Cyclosorus interruptus	39
Thelypteridaceae	Christella	Christella parasitica	49
Polypodiaceae	Microsorum	Microsorum punctatum	7
Polypodiaceae	Phymatosorus	Phymatosorus scolopendria	1
Selaginellaceae	Selaginella	Selaginella moellendorffii	3
Dryopteridaceae	Nephrolepis	Nephrolepis biserrata	544
Dryopteridaceae	Phanerophlebia	Phanerophlebia umbonata	124
Pteridaceae	Pityrogramma	Pityrogramma calomelanos	15
Pteridaceae	Pteris	Pteris vittata	74

Family	Genus	Species	Number of Individuals
Lygodiaceae	Lygodium	Lygodium microphyllum	52
Lygodiaceae	Lygodium	Lygodium flexuosum	1
Lygodiaceae	Lygodium	Lygodium circinnatum	10
Blechnaceae	Stenochlaena	Stenochlaena palustris	159

The inventory data indicate that *Gleichenia linearis* was the most abundant fern species in the study area, followed by *Nephrolepis exaltata* and *Nephrolepis biserrata*, which were also frequently observed across a range of coastal habitats. These species were predominantly found in open coastal areas with moist, well-drained conditions, reflecting their broad ecological tolerance and adaptability to the dynamic environmental conditions of Waai Village, including variations in salinity, sunlight exposure, and periodic water fluctuations. In contrast, species such as *Phymatosorus scolopendria* and *Lygodium flexuosum* were recorded in much smaller numbers, indicating more restricted distributions and narrower ecological niches, often associated with specific microhabitats. This variation in species abundance and habitat preference highlights the heterogeneity of the coastal ecosystem and the diverse adaptive strategies of the local fern community. The detailed distribution and abundance patterns provide valuable empirical data that can be directly utilized to develop contextually relevant teaching materials for the Lower Plant Botany course, enabling students to connect botanical concepts with real environmental conditions.

The inventory data also show ecological variation among the recorded fern species, indicating that the coastal area of Waai Village provides heterogeneous microhabitats that support different growth forms and habitat preferences. Several species, such as *Gleichenia linearis* and *Lygodium microphyllum*, were commonly associated with open and relatively moist habitats, while species such as *Davallia repens*, *Phanerophlebia umbonata*, and *Phymatosorus scolopendria* were more closely associated with shaded habitats or epiphytic growth on other plants. In contrast, *Cyclosorus interruptus* tended to occur in very humid or water-associated microhabitats. This ecological variation strengthens the value of the inventory as a basis for contextual teaching materials, because students are not only introduced to taxonomic diversity but also to differences in habitat preference and ecological adaptation among local fern species.

Table 5. Ecological Summary of Fern Species Identified in the Coastal Area of Waai Village

No.	Species	Growth form	General habitat tendency	Microhabitat note
1	*Nephrolepis exaltata*	Terrestrial	Moist coastal ground	Found on ground with relatively moist conditions
2	*Gleichenia linearis*	Terrestrial	Open coastal area	Common in open sites and tends to cover the ground surface
3	*Blechnopsis orientalis*	Terrestrial	Open to semi-open ground	Found on ground with strong rhizomatous growth
4	*Davallia repens*	Terrestrial / epiphytic	Humid and shaded habitat	Occurs on ground or attached to supporting plants in moist places
5	*Davallia fajeensis*	Terrestrial	Humid ground habitat	Recorded in low abundance on moist terrestrial substrate
6	*Palhinhaea cernua*	Terrestrial	Open or semi-open sites	Found on ground, including relatively poor soils and forest edges

No.	Species	Growth form	General habitat tendency	Microhabitat note
7	*Cyclosorus interruptus*	Terrestrial	Very humid / water-associated habitat	Associated with very moist places and areas with standing water
8	*Christella parasitica*	Terrestrial	Humid ground habitat	Commonly associated with moist terrestrial habitat
9	*Microsorum punctatum*	Epiphytic	Tree-associated habitat	Found attached to supporting plants; short-stalked simple fronds
10	*Phymatosorus scolopendria*	Epiphytic	Shaded tree-trunk habitat	Recorded on tree trunks in shaded conditions
11	*Selaginella moellendorffii*	Terrestrial	Humid ground surface	Forms dense ground cover in humid microsites
12	*Nephrolepis biserrata*	Terrestrial / epiphytic	Humid ground and near vegetation	Grows in clumps on ground or close to supporting vegetation
13	*Phanerophlebia umbonata*	Terrestrial / epiphytic	Humid and shaded habitat	Associated with moist, shaded habitat under vegetation cover
14	*Pityrogramma calomelanos*	Terrestrial	Open rocky or exposed habitat	Often found in open places, including rocky ground
15	*Pteris vittata*	Terrestrial	Open ground habitat	Found on terrestrial substrate in relatively open conditions
16	*Lygodium microphyllum*	Climbing fern	Open and humid habitat	Twines around nearby vegetation and may form colonies
17	*Lygodium flexuosum*	Climbing fern	Open habitat with supporting vegetation	Climbs and twines on nearby plants
18	*Lygodium circinnatum*	Climbing fern / epiphytic tendency	Open habitat with sufficient light	Often climbs on surrounding plants in exposed sites
19	*Stenochlaena palustris*	Terrestrial / climbing	Humid ground and supporting vegetation	Grows on the ground or climbs nearby plants in moist habitat

Display of the Developed Supplementary Teaching Material

To provide a clearer representation of the developed product, several representative pages of the PDF-based supplementary teaching material are presented in Figure 2.

Figure 2. Representative pages of the developed PDF-based supplementary teaching material

These pages illustrate the general structure, visual layout, and integration of local ecological inventory data into the content of the material. The selected pages are intended to show how the fern inventory findings from the coastal area of Waai Village were transformed into contextual teaching content for the Lower Plant Botany course. The presented pages provide an overview of the structure, layout, and content organization of the developed supplementary teaching material. These pages also illustrate how local ecological inventory data from Waai Village are incorporated into the material within a pedagogically structured format. These examples are intended to support the subsequent stages of expert validation and readability assessment.

Expert Validation Results

In addition to the ecological inventory data, this study presents the results of expert validation conducted to assess the feasibility and quality of the developed supplementary teaching materials for the Lower Plant Botany course. This process aimed to ensure that the materials met academic, pedagogical, and linguistic standards, confirming their suitability for use by preservice biology teachers prior to readability testing. The validation involved three experts: a subject matter expert evaluating the accuracy and completeness of the Pteridophyta content, an instructional media expert assessing layout, visual integration, and usability, and a language expert examining clarity, grammar, terminology consistency, and appropriateness for undergraduate students. Each expert used a structured four-point Likert scale based on predefined indicators, and the data were analyzed descriptively by calculating mean scores and converting them into percentage values to determine the overall validity level of the materials.

Table 6. Expert Validation Results of the Supplementary Teaching Materials

Validator	Aspect Assessed	Mean Score	Validity (%)	Category
Material	- Alignment with Course Learning Outcomes (CLOs/LOs)	3.0	75	Valid
	- Conceptual accuracy of Pteridophyta	3.2	81	Very Valid
	- Depth and breadth of content	2.9	73	Valid
	- Accuracy of scientific terminology and classification	3.0	75	Valid
	- Integration of local ecological context (Waai Village)	3.2	80	Valid
Media	- Systematic presentation of content	3.1	79	Valid
	- Layout consistency	2.9	73	Valid
	- Integration of text, images, and tables	3.0	75	Valid
	- Visual readability	3.2	81	Very Valid
Language	- Support for independent learning	3.1	79	Valid
	- Sentence clarity	3.0	75	Valid
	- Grammatical accuracy	3.1	79	Valid
	- Consistency of scientific terminology	3.2	81	Very Valid
	- Appropriateness of language level for undergraduate students	3.0	75	Valid
	- Overall text readability	3.1	79	Valid
Average		3.05	79.0	Valid

The expert validation results indicate that all indicators across material, media, and language aspects were assessed as valid. Experts suggested minor revisions, mainly regarding layout adjustments, clarification of some sentences, and minor improvements in image labeling. Overall, the materials are considered suitable for instructional use with these minor refinements.

The overall expert validity score of 79.0% indicates that the developed material met the criteria for validity, although the result also suggests that refinement was still necessary in several aspects of presentation and clarity. In this study, the expert comments did not indicate fundamental weaknesses in the product content, but pointed to the need for targeted improvements in layout consistency, sentence formulation, and image labeling. Therefore, the validation results should be interpreted as evidence that the product was feasible for use after revision, rather than as evidence of a fully finalized product without revision needs.

Table 7. Revision Log Based on Expert Validation

Validator Domain	Comment/Suggestion	Revision Made	Location in Product
Material	Several parts of the explanation required clearer wording to improve conceptual clarity of Pteridophyta content.	Selected sentences were revised to improve clarity and reduce ambiguity in concept explanation.	Introductory section and species explanation pages
Media	Layout consistency needed improvement in several parts of the material.	Layout arrangement was adjusted to improve consistency of spacing, alignment, and visual organization.	Cover and content layout pages
Media	Some images and visual components required clearer labeling.	Image labels and captions were revised to make visual references clearer and easier to follow.	Species-based pages
Language	Several sentences required clarification and refinement of wording.	Sentence structure and diction were revised to improve readability for undergraduate students.	Introductory section and species explanation pages

Student Readability Results

Following expert validation, a readability test was conducted to evaluate students' perceptions of clarity, comprehensibility, and usability of the teaching materials. The readability assessment involved undergraduate students of the Biology Education Study Program who had taken or were taking the Lower Plant Botany course. Students completed a readability questionnaire using a four-point Likert scale. The assessment focused on language clarity, conceptual understanding, visual readability, contextual relevance, and support for independent learning.

The readability test involved 20 third-semester undergraduate students of the Biology Education Study Program, Universitas Pattimura, who were taking the Lower Plant Botany course, and the questionnaire was completed anonymously. The high readability scores across all aspects indicate that the developed material was generally perceived as clear, relevant, and easy to use. However, these results should be interpreted as student perceptions of readability rather than as direct evidence of improved learning outcomes. In particular, the high score for the relevance of examples and local context suggests that students perceived the integration of local fern inventory data as helpful in connecting Pteridophyta concepts with real environmental conditions.

Table 8. Student Readability Test Results

Readability Aspect	Mean Score	Readability (%)	Category
- Clarity of text and sentences	3.72	93.00	Very Good
- Ease of understanding Pteridophyta concepts	3.68	92.00	Very Good
- Appropriateness of language level	3.75	93.75	Very Good
- Visual readability (images, tables, diagrams)	3.70	92.50	Very Good
- Relevance of examples and local context	3.80	95.00	Very Good
- Support for independent learning	3.73	93.25	Very Good

The readability results indicate that all assessed aspects were rated as good to very good. Among these aspects, contextual relevance received the highest score, suggesting that the integration of local fern inventory data from the coastal area of Waai Village was perceived by students as helpful for understanding Pteridophyta concepts. These results reflect the clarity, comprehensibility, and contextual alignment of the developed learning materials from the students' perspective.

Discussion

Local Inventory as a Foundation for Contextual Content

The development of biology teaching materials based on local potential represents a relevant approach to addressing the need for contextual learning in higher education (Sugiarto et al., 2025). In the present study, the inventory of 19 fern species from the coastal area of Waai Village provided an empirical basis for developing supplementary teaching materials for the Lower Plant Botany course. The use of locally documented species in the developed material allowed Pteridophyta content to be presented in relation to real environmental conditions rather than only through general textual explanation.

This orientation is consistent with the view that instructional materials integrating local potential can help connect biological concepts with students' real environmental contexts (Rengkuan et al., 2026). Previous studies have also shown that local wisdom values can be integrated into biology learning design for preservice teachers, although such integration still requires reinforcement through more systematic material development (Khairunisa et al., 2025). In this study, the inventory findings did not function merely as supporting background, but as the primary source for contextual species-based content related to morphology, habitat, and classification.

The diversity of fern species identified in this study also contributed to the depth of the developed teaching material because it enabled the presentation of multiple forms of ecological and taxonomic variation within a single local ecosystem. This is important because learning about Pteridophyta requires students to understand the relationship among morphological characteristics, habitat preference, and classification. The developed material therefore benefited from the availability of local species data that could illustrate those relationships in a more grounded and observable way.

The use of environment-based learning resources has been reported to help students understand and manage biological information more effectively (Sari et al., 2025). This orientation is also in line with ethnopedagogical perspectives that emphasize the role of cultural and local contexts in science learning (Sakti et al., 2024). Accordingly, the use of the Waai coastal ecosystem in the developed material may be understood as a contextual strategy for presenting botanical content in a form that is more relevant to preservice biology teachers.

Meaning of Expert Validity Outcomes for Product Quality

The expert validation results showed that the developed supplementary teaching material achieved an overall validity score of 79.0%, which indicates that the product was valid and feasible for use after revision. This result suggests that the product had met basic academic, pedagogical, and linguistic standards, although refinement was still required in several aspects. Therefore, the validity results in this study should be interpreted as evidence of product feasibility rather than as evidence of a fully finalized product without revision needs.

The relevance of the teaching material content was examined through validation by material, media, and language experts. A valid category in expert judgment indicates that the substance, structure, and presentation of the material were considered generally appropriate for instructional use. In this study, the material aspect was rated valid, which suggests that the developed content had sufficiently represented the core concepts of Pteridophyta in relation to the intended course needs.

The alignment of teaching materials with intended course learning outcomes is emphasized in constructive alignment theory, in which learning outcomes, instructional content, and assessment are designed coherently to support student achievement of competencies. Validation by subject-matter experts is also necessary to ensure the accuracy and appropriateness of academic content before instructional implementation (Du Preez & Jacobs, 2025). From this perspective, the validity result supports the conclusion that the material was academically acceptable as a supplementary resource for the Lower Plant Botany course.

From the media and language perspectives, the valid ratings indicate that the layout, structure, readability, and wording of the material were generally suitable for undergraduate students. Clear structure, consistent layout, and ease of navigation are recognized as important features of effective instructional media in higher education (Banat & Wahba, 2023). Language clarity has likewise been reported to contribute to readability and conceptual understanding in instructional materials (Bansiong & Wan, 2019). In this study, revision comments related to layout consistency, sentence clarification, and image labeling should therefore be interpreted as refinement points rather than as evidence of fundamental product weakness.

Meaning of Readability Outcomes and the Role of Local Context

The readability test showed that all assessed aspects were rated in the very good category, with percentage scores ranging from 92.00% to 95.00%. These findings indicate that the developed material was perceived by students as clear, readable, and relevant to their learning needs. The highest score was obtained for the relevance of examples and local context, which suggests that students perceived the use of local fern data from Waai Village as helpful in understanding Pteridophyta content.

This result is particularly important because the developed product was intended as a supplementary teaching material for undergraduate students who were studying Lower Plant Botany. In this context, the readability findings indicate that the content, language, and presentation were considered accessible by the target users. The results also support the view that local ecological examples can enhance the perceived relevance of the material from the students' perspective.

The readability of teaching materials has been reported to increase when content is linked to contexts that are familiar to students (Fayzullina et al., 2023). Context-based learning is also regarded as important in higher education because it supports understanding through connections with real-world situations, particularly in environment-based science learning (Toan et al., 2025). In the present study, the local context of Waai Village appears to have contributed positively to the perceived comprehensibility of the material.

At the same time, the readability findings should be interpreted cautiously. The present study measured students' perceptions of clarity, usability, and contextual relevance, but it did not measure conceptual gain or instructional effectiveness. Therefore, the readability results should be understood as evidence that the material was perceived as supportive of understanding, not as direct evidence that it improved learning outcomes. In this sense, the role of local context in the present study can be discussed as a potential facilitating factor rather than as a proven source of learning gain.

Limitations and Future Research

This study has several limitations that should be acknowledged. First, the study was limited to product development, expert validation, and student readability testing, and it did not include classroom implementation or effectiveness testing. As a result, the study cannot yet demonstrate whether the developed material improves conceptual understanding, scientific literacy, or other learning outcomes in actual instructional settings.

Second, the dissemination stage was conducted in a limited manner, so the product has not yet been tested in broader instructional contexts. Third, the validation process involved one validator for each domain, which is adequate for initial feasibility judgment but does not provide multi-rater agreement within the same validation aspect. These limitations indicate that the findings of this study should be positioned at the level of product feasibility and perceived readability rather than at the level of demonstrated instructional impact.

Several studies recommend quasi-experimental designs to evaluate the effect of contextual teaching materials on conceptual understanding and scientific literacy (Hernandez Gonzalez, 2023). Future studies may therefore examine the effectiveness of the developed material through classroom implementation, usability observation, or quasi-experimental comparison. Such studies would strengthen the empirical position of the product by moving beyond feasibility and readability toward evidence of instructional impact.

The present study nevertheless suggests that teaching materials grounded in local ecological potential may serve as relevant supplementary resources in preservice biology teacher education. Teaching materials based on local potential can function not only as learning resources but also as examples of contextual pedagogical strategies in teacher preparation (Behling et al., 2025). Preservice teachers who are accustomed to using environment-based teaching materials may also be better prepared to connect biological content with the realities of schools and communities where they will later teach (Subramaniam, 2020). Accordingly, the main contribution of this study lies in showing that local inventory data can be transformed into valid and highly readable contextual content for Lower Plant Botany, while further research is still needed to examine its broader instructional effectiveness.

CONCLUSION

This study developed supplementary teaching materials for the Lower Plant Botany course focusing on Pteridophyta based on ecological inventory data from the coastal area of Waai Village, Maluku, using the Four-D (4D) development model. The developed material integrated local fern diversity as the primary content basis, enabling botanical concepts to be presented in a more contextual manner. Expert validation showed that the material achieved an average validity score of 79.0%, indicating that it was valid and feasible for instructional use after revision. Student readability results ranged from 92.00% to 95.00%, indicating that the material was perceived as very good in terms of clarity, contextual relevance, visual readability, and support for independent learning. These findings indicate that supplementary teaching materials based on local ecological potential can serve as feasible contextual resources for the Lower Plant Botany course in preservice biology teacher education. However, this study was limited to product development, validation, and readability testing, and did not examine the effectiveness of the material in improving learning outcomes. Therefore, further studies are needed to evaluate its instructional effectiveness in actual classroom settings.

RECOMMENDATION

Based on the findings of this study, several recommendations can be proposed for future research and educational practice. First, future studies are recommended to examine the effectiveness of the developed supplementary teaching materials in real classroom settings using quasi-experimental or pretest-posttest designs. Outcomes that may be measured include conceptual understanding of Pteridophyta, scientific literacy, learning motivation, and independent learning ability. Relevant instruments may include conceptual understanding tests, scientific literacy tests, learning motivation questionnaires, and classroom observation sheets.

Second, future research may expand the development of supplementary teaching materials based on local ecological potential to other biology topics, such as ecology, biodiversity, plant taxonomy, and conservation biology. This expansion would strengthen the integration of local environmental resources into biology education and provide more diverse contextual learning materials for preservice biology teachers. Third, broader ecological inventory studies in coastal and terrestrial ecosystems are recommended to enrich the database of local biological resources that can be transformed into instructional materials. Finally, universities and biology education programs are encouraged to support the systematic integration of local potential into teaching material development in order to prepare preservice biology teachers who are able to design contextual learning experiences connected to real environmental conditions.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Prelly Marsel Jolanda Tuapattinaya	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Pamella Mercy Papilaya		✓		✓		✓		✓		✓		✓		
Sendy Putra Pradana	✓	✓		✓		✓				✓	✓	✓	✓	

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper.

INFORMED CONSENT

Informed consent was obtained from all participants involved in the expert validation and student readability assessment. Participation was voluntary, and student responses were collected anonymously for research purposes.

ETHICAL APPROVAL

This study involved ecological inventory, educational product development, expert validation, and anonymous student readability assessment. No invasive procedures, clinical intervention, or collection of sensitive personal data were conducted. Therefore, formal ethical approval was not required. All research procedures were carried out in accordance with ethical principles of voluntary participation, confidentiality, and academic integrity.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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