RESEARCH ARTICLE

Improving biodiversity literacy through flipped classroom assisted by pteridophyte identification worksheets in Masigit Kareumbi

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Abstract

Background: The limited allocation of face-to-face time and the high prevalence of plant blindness lead to plant world learning that tends to be theoretical and memorization-oriented, thereby contributing to students' low biodiversity literacy. **Objectives**: This study aims to analyze the effect of applying the Flipped Classroom model, assisted by worksheet identification of Pteridophyte, on students' biodiversity literacy skills in the Mount Masigit Kareumbi area. **Methods:** A quasi-experimental non-equivalent control group design involved 70 students, selected through cluster random sampling and divided into experimental (n = 35) and control (n = 35) classes. The intervention was conducted in two sessions, each lasting three lessons. Data were collected using written tests, observations, and questionnaires, then analyzed using N-Gain and independent-samples t-tests. Both groups showed equivalent baseline performance, with an identical mean pretest score of 37.0. **Results**: The results showed that the experimental class obtained an average posttest score of 62.9, with an N-Gain of 0,51 (medium), higher than the control class, which had a posttest score of 50.9 and an N-Gain of 0,28 (low). The difference was statistically significant ($p = 0.019$), with a Cohen's d value of 0.392, indicating a medium effect size. Student responses to the learning process were very good, with an average of 93.9%. **Conclusions**: Thus, implementing the Flipped Classroom model, supported by student worksheets tailored to local potential, effectively increased students' biodiversity literacy and ecological awareness. This study provides a practical guide for utilizing local conservation resources as active biology learning tools.

Keywords: biodiversity literacy; flipped classroom; pteridophyte; worksheet

Introduction

Contemporary science education increasingly shifts away from rote taxonomic memorization toward fostering the 21st-century competencies, particularly biodiversity literacy. As conceptualized by Leksono et al. (2015), define biodiversity literacy as the capacity to comprehend, articulate, and apply ecological principles to real-world contexts while using critical thinking to resolve environmental issues. Fostering this competency is especially urgent in Indonesia, which accounts for approximately 17% of global biodiversity and ranks among the world's most species-rich and endemic nations, according to the National Research and Innovation Agency (*Badan Riset dan Inovasi Nasional*/BRIN) via Shmelev (2023). This vast biodiversity entails a profound responsibility for environmental conservation. As Wetering et al. (2022) stress, rich biodiversity serves as a foundational pillar for sustainable environmental education.

In line with Education for Sustainable Development (ESD) principles, Fajri et al. (2025) contend that contextualized learning fosters students' ecological awareness and commitment to sustainability. Ultimately, as Hooykaas et al. (2022) Consequently, enhancing biodiversity literacy is critical for cultivating a generation dedicated to environmental responsibility and conservation values.

Empirical evidence indicates that students' biodiversity literacy remains constrained, influenced by foundational scientific deficits and specific cognitive biases. Globally, results from the 2022 Programmed for International Student Assessment (PISA) reveal that Indonesian students struggle with core scientific literacy, particularly in interpreting data, applying concepts, and solving contextual problems (OECD, 2023). In addition to these broader limitations, biology education confronts a distinct cognitive barrier termed "plant blindness" the tendency to ignore plant species and underestimate their ecological roles (Thomas et al., 2022). These two issues are deeply interconnected: basic scientific literacy offers the cognitive structure required to process complex ecological systems, whereas weak reasoning skills hinder students' ability to overcome perceptual biases such as plant blindness (Stagg et al., 2025). Thus, the interplay between limited scientific reasoning and unaddressed plant blindness creates a major obstacle to advancing biodiversity literacy.

In Indonesian biology classrooms, passive instructional approaches and textbook dependency often exacerbate this cognitive bias (Amprazis & Papadopoulou, 2026). Traditional teaching methods frequently reduce complex botanical topics to rote memorization, hindering comprehensive understanding of ecological networks (Albuquerque et al., 2025). As a result, critical topics such as plant diversity specifically Pteridophyte (ferns) are commonly delivered through rigid taxonomic drills rather than being applied to investigate ecological relationships and conservation (Maskour et al., 2019). To overcome these instructional limitations, Parsley (2020) advocates for active, immersive pedagogical strategies to reignite student interest in botany. Specifically, the Flipped Classroom model reorganizes instruction by moving foundational botanical theory to asynchronous pre-class study, thereby reserving synchronous sessions for practical plant identification, collaborative problem-solving, and field inquiry that directly counter plant blindness (Awidi & Paynter, 2019; Balding & Williams, 2016).

One factor influencing students' low biodiversity literacy is the limited time for learning in class (Ee et al., 2018). Interviews with biology teachers at a high school in Bandung Regency indicate that students still struggle to distinguish the morphological characteristics of Plantae because the learning process is dominated by lectures without direct identification activities. The limited instructional time, worsened by the dominance of one-way teaching, ultimately limits the depth of analysis of the morphology and ecology of Pteridophyte, thus resulting in low retention of students' scientific understanding and literacy (Woods & Copur-Gencturk, 2024). Ideally, to build comprehensive biodiversity literacy competencies, learning activities should be contextual, exploratory, and encourage student independence (Ladosz et al., 2022). The Flipped Classroom serves as a viable alternative, enabling students to engage with foundational concepts independently prior to face-to-face sessions (Akçayır & Akçayır, 2018). Consequently, in-person instruction can prioritize discussions, problem-solving, and collaborative tasks aimed at developing biodiversity literacy skills (Lo & Hew, 2017). Integrating structured worksheets offers crucial scaffolding for self-directed study, thereby reinforcing overall instructional efficacy. In the present study, Pteridophyte identification worksheets contextualized to the Mount Masigit Kareumbi area were enhanced using exploratory videos and Google Earth features. Incorporating these digital components provides realistic depictions of natural habitats, enabling students to analyze fern morphological traits within an authentic ecological setting (Lestari et al., 2023).

Although extensive literature documents the cognitive benefits of the Flipped Classroom in biology education (Cabı, 2018). Meanwhile, recent ecological assessments highlight significant species literacy deficits and widespread detachment from local biodiversity among students (Hooykaas et al., 2019). Although biodiversity-focused initiatives (Hazard et al., 2018) and contextual student worksheets (Kembuan et al., 2019) strive to enhance active learning, such interventions typically depend on traditional, classroom-bound models that lack asynchronous digital preparation. Consequently, current research evaluates these educational strategies independently, revealing a distinct gap concerning the integration of flipped learning with localized taxonomic resources to address species literacy deficits.

To bridge these instructional limitations, this study introduces an integrative approach that merges asynchronous Flipped Classroom learning with contextualized Pteridophyte identification worksheets derived from the Mount Masigit Kareumbi Conservation Area. Pteridophyte species from this reserve were selected because their rich, distinct morphological traits provide an optimal framework for developing abstract taxonomic reasoning. By establishing this framework, the study illustrates how regional conservation assets can be transformed into digital pre class scaffolding, turning passive plant recognition into active literacy development. Distinct from previous studies that solely diagnose species literacy deficits or evaluate flipped instruction in abstract domains, this research directly examines the synergistic impact of digital pre-class preparation and hands on local species identification across three key biodiversity literacy dimensions: concept application, problem solving, and scientific communication.

Based on these problems, this study aims to analyze the effectiveness of the Flipped Classroom model, supported by the Pteridophyte Identification Student Worksheet, in the Mount Masigit Kareumbi Area on biodiversity literacy skills. This study compares the biodiversity literacy achievements between the experimental and control classes, and identifies the implementation of the model and student responses to the applied learning. This study is expected to provide empirical contributions in the development of local biodiversity-based biology learning that supports the strengthening of students' biodiversity literacy.

Method

Research design

This study employed a quantitative quasi-experimental design with a non-equivalent control group. The analysis focuses on comparing the increase in students' biodiversity literacy after applying the Flipped Classroom model, assisted by the Pteridophyte identification worksheet, which integrates data from the Masigit Kareumbi Area, and the control class, which was taught using a conventional Discovery Learning model. Through an unequal control group scheme, Sugiyono (2019) presents in Table 1.

Table 1. Visual design of non-equivalent control group design

No	Group	Pretest	Treatment	Posttest
1.	Experimental	O_1	X	O_2
2.	Control	O_3	-	O_4

Population and sample

The study population included 140 10th-grade students at PTI Senior High School (pseudonym) during the 2025/2026 academic year across four classes. A sample of two classes was drawn using cluster random sampling. This strategy was chosen because participants were organized into intact classroom units, preventing individual reassignment in order to maintain a natural instructional setting (Handley et al., 2018). Accordingly, group designations for both the experimental and control cohorts were determined through a randomized selection process. Before group allocation, baseline academic equivalence among the four candidate classes was verified using prior exam scores, confirming similar foundational competence in biology. Subsequently, a digital spin wheel draw served as the cluster random sampling technique to allocate intact classes to either the experimental or control condition. The final distribution of participants selected for the study sample following this random selection is summarized in Table 2.

Table 2. Distribution of research sample

No	Group	Class	Number of Students
1.	Control Class	X-3	35
2.	Experimental Class	X-1	35

Data collection technique

Data collection relied on three principal techniques: written assessments, questionnaires, and classroom observations. Observation sheets tracked procedural fidelity across all instructional stages, while questionnaires gathered student perceptions following the intervention. To assess biodiversity literacy skills, a written test was structured around three core indicators adapted from Oktaviana et al. (2022), he ability to apply concepts, solve problems, and communicate biodiversity values. Before field administration, all research instruments underwent expert validation. The student worksheets, derived from empirical field surveys at the study site, were evaluated by two biology education experts: a botanical taxonomist specializing in plant morphology and classification, and an educational technology specialist with expertise in AI integration, instructional design, and digital media. A 13-item rubric evaluated content validity across material accuracy, item precision, recency, content quality, and alignment with biodiversity literacy goals. Likewise, media validity was appraised using a 22-item rubric examining layout, linguistic clarity, graphic design, user engagement, and operational functionality. This review yielded validity scores of 73.8% for content and 85.4% for media, placing both instruments well within standard acceptable thresholds for educational research. Although the content score satisfied validity criteria, minor complexities in taxonomic terminology were noted and iteratively refined in response to expert feedback.

Furthermore, two supervising faculty members examined and refined the remaining instruments including the achievement test, observation sheets, and questionnaires to ensure construct alignment, readability, and methodological rigor. Additionally, two supervising faculty members reviewed and refined the remaining instruments comprising the achievement test, observation sheets, and questionnaires to guarantee construct alignment, readability, and methodological accuracy. For the biodiversity literacy test instrument, an initial field trial was conducted on 20 multiple choice questions to analyze validity, difficulty level, and discriminating power. Based on the analysis, 15 questions met the empirical criteria for use (Ch & Saha, 2022). The reliability test shows a coefficient of 0.72, indicating the instrument's consistency is in the high category (Sugiyono, 2019). The distribution of test items for each biodiversity literacy indicator is presented in detail in Table 3.

Table 3. Biodiversity literacy item test instrument

No	Biodiversity literacy indicators	Items	Question number
1.	Applying biodiversity concept	5	2, 5, 8, 11, 14
2.	Solving biodiversity problems	5	3, 6, 9, 12, 15
3.	Communicating the biodiversity	5	1, 4, 7, 10, 13

Data analysis was conducted using both descriptive and inferential statistical approaches. First, learning gain was calculated using the normalized gain (N-Gain) formula to determine the increase in students biodiversity literacy skills before and after the intervention, categorized into low, medium, and high levels. Prior to hypothesis testing, parametric assumptions were examined using the Shapiro-Wilk test for data normality and Levene's test for homogeneity of variance. Upon satisfying these assumptions, an Independent Sample t-Test was conducted at a significance level of $\alpha = 0.05$ to evaluate whether a statistically significant difference existed in N-Gain scores between the experimental and control groups. Furthermore, Cohen's d effect size was calculated to determine the practical magnitude of the intervention's impact on learning gains, interpreted against established statistical benchmarks. Additionally, descriptive percentage statistics were used to analyze observation protocols and student questionnaire data, evaluating implementation fidelity and participant perceptions.

Procedure

Overall, the research unfolded across three primary phases: preparation, implementation, and data collection. During the implementation phase, the experimental cohort learned through a modified Flipped Classroom model supported by local biodiversity-focused worksheets *(LKPD)*, structured according to the pedagogical framework adapted from (Bergmann & Sams, 2012). The instructional workflow for the Flipped Classroom model applied in the experimental group is outlined in Figure 1.

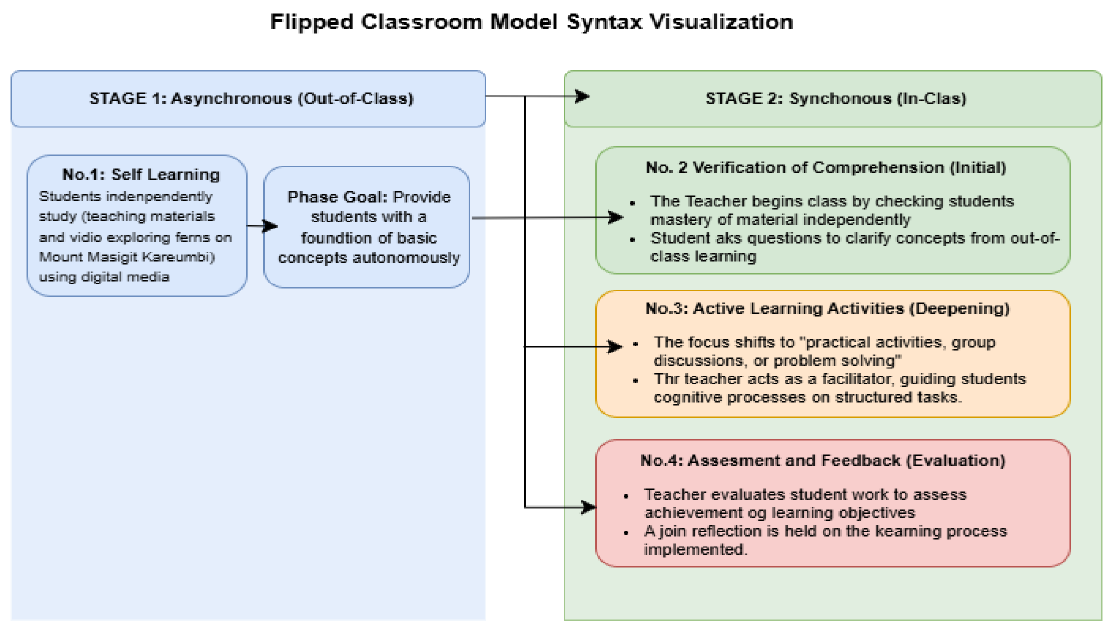

Figure 1. Flipped classroom model syntax

Conversely, the control group was taught via a conventional Discovery Learning model paired with the 5M scientific approach (observing, questioning, gathering information, associating, and communicating). While both cohorts covered identical core content on Pteridophyte, instruction for the control group took place entirely synchronously within standard classroom hours, relying on conventional worksheets without asynchronous digital pre-class preparation.

Results and Discussion

Pteridophyta identification worksheets profile

The present study introduced a contextual digital worksheet developed to assess and foster biodiversity literacy. Rather than depending on abstract theoretical examples, the instructional material derives directly from empirical field survey data gathered at the study site. Unlike traditional learning resources that rely on generic illustrations, integrating authentic images of native specimens transforms abstract taxonomic features into tangible observational anchors, thereby reducing cognitive load while promoting higher-order biodiversity literacy skills. Student learning tasks directly incorporate the 14 documented local Pteridophyte species, as listed in Table 4.

Table 4. Identification of local Pteridophyte species integrated into the worksheets

No	Local Name	Scientific Name	Genus	Family
1.	*Pakis kayu spinulosa*	*Dryopteris carthusiana*	Dryopteris	Polypodiaceae
2.	*Paku Jantan*	*Dryopteris filix-mas*	Dryopteris	Polypodiaceae
3.	*Paku pedang / Paku karat*	*Nephrolepis cordifolia*	Nephrolepis	Polypodiaceae
4.	*Paku gendong*	*Diplazium proliferum*	Diplazium	Aspleniaceae
5.	*Paku sarang burung*	*Asplenium nidus*	Asplenium	Aspleniaceae
6.	*Paku tiang*	*Sphaeropteris glauca*	Sphaeropteris	Cyatheaceae
7.	*Paku suplir*	*Adiantum sp.*	Adiantum	Pteridaceae
8.	*Paku monyet*	*Cibotium barometz*	Cibotium	Cyatheaceae
9.	*Paku gajah*	*Angiopteris evecta*	Angiopteris	Marattiaceae
10.	*Paku geulis (andam dangdeur)*	*Pteridium aquilinum*	Pteridium	Dennstaedtiaceae
11.	*Paku Sayur*	*Diplazium esculentum*	Diplazium	Aspleniaceae
12.	*Paku Hokuto*	*Tectaria hokutoensis (Hayata) C.Chr.*	Tectaria	Tectariaceae
13.	*Paku cakar ayam*	*Selaginella doederleinii*	Selaginella	Selaginellaceae
14.	*Paku Sisik Naga*	*Pyrrosia piloselloides*	Pyrrosia	Polypodiaceae

Functioning as the main instructional stimulus, the worksheet includes a visual gallery of this documented local flora, utilizing morphological photographs of native fern species to guide student observations, as displayed in Figure 2.

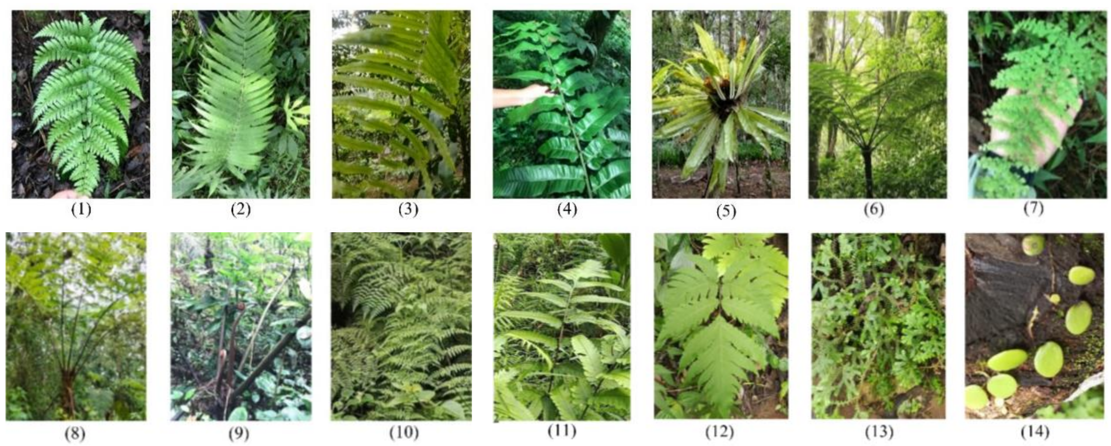

Figure 2. Morphological variations of the Pteridophyte species identified at the study site.

Incorporating local Pteridophyte species from Gunung Masigit Kareumbi into the worksheets offered students a contextualized, real-world learning experience. By contrasting terrestrial ferns thriving on the forest floor with epiphytic species adapted to tree canopies, the instructional material effectively highlighted distinct ecological niches. This contextual approach linked theoretical biological concepts to concrete environmental observations, fostering gains in students biodiversity literacy (Susanto, 2017). Focusing on specific morphological traits such as structural adaptations for terrestrial versus epiphytic survival helped the worksheets reduce plant blindness among participants. Direct interaction with authentic field specimens encouraged students to recognize local flora instead of viewing plants as an undifferentiated green backdrop. Consequently, these structural observations strengthened their ability to solve environmental problems when dealing with real-world ecological issues (Suryawati & Osman, 2017).

Implementation of learning

Both teacher and student engagement were assessed in each session using a structured observation sheet formatted with a Guttman scale (Implemented/Not Implemented). To safeguard objectivity, an experienced mentor teacher carried out the observation protocol, monitoring instructional fidelity across three sequential phases: introduction, core activities, and closing. The observer completed the standardized rubric based on real-time classroom activities. A summary of the implementation percentages for both the experimental and control classes is systematically presented in Table 5.

Table 5. Results of teacher and student activity implementation

Group	Meeting	Teacher Activity			Students Activity		
		Value (%)	Average	Category	Value (%)	Average	Category
Experiment	1	100	95.8	Excellent	91.6	91.6	Excellent
	2	91.6			91.6		
Control	1	97.9	98.9	Excellent	97.9	98.9	Excellent
	2	100			100		

The implementation of learning in the experimental class using the Flipped Classroom model went very well. The increase in teacher and student activity from the first to the second meeting was driven by the effectiveness of independent learning activities at home (pre-class). Based on the previously studied digital materials, students already had a basic understanding before class began. This made the introductory class time much more efficient. Rather than spending class time on passive theoretical lectures, the teacher could focus directly on activating students prior knowledge through interactive discussions and stimulating motivation to connect their pre-class understanding with practical tasks (Brandon, 2020). This initial knowledge capital has been proven to make it easier for experimental class students to complete tasks in the modified worksheets, such as using determination keys and analyzing the characteristics of Pteridophyte in groups. (Förster et al., 2022). From a pedagogical perspective, this trend aligns with Self-Regulated Learning (SRL) theory, particularly its forethought and performance stages (Dent & Koenka, 2016). Furthermore, establishing foundational mental schemas of fern taxonomy prior to class functions as a pretraining effect within Cognitive Load Theory (CLT). This pretraining reduces extraneous cognitive load during face-to-face sessions, thereby liberating working memory capacity for complex taxonomic reasoning (Mayer, 2021; Sweller, 2020).

Implementation fidelity within the control group using Discovery Learning averaged 98.9%, rising from 97.9% to 100%. This high level of compliance stems from teacher and student familiarity with standard face-to-face classroom routines during school hours, which function independently of digital technology (Aldalur & Perez, 2023). comparison, implementation fidelity in the experimental class was slightly lower at 95.8%. Although Guttman scale metrics confirmed full execution of the Flipped Classroom syntax, qualitative field observations identified minor variations during asynchronous pre-class study. Student engagement with video materials accessed through QR codes reached 82%, reflecting strong interest in visual media. Conversely, engagement with text-based module reading declined sharply to 68%. Baig & Yadegaridehkordi (2023), note that such disparities often stem from a preference for concise visual resources, unstable home internet connectivity, and competing non-academic responsibilities. As a result, inconsistent pre-class preparation creates gaps in knowledge acquisition, impacting student readiness and self-directed time management (Dalbani et al., 2022; Zhong, 2024). heoretically, active engagement in the control cohort aligns with core constructivist principles, where learners build taxonomic knowledge through direct morphological exploration (Saad et al., 2025), anchored by prior apperception (Morris, 2025).

Notably, despite the minor shortfall in pre-class task completion, the experimental cohort achieved significantly higher biodiversity literacy gains than the control group. This outcome highlights a critical pedagogical distinction: while the control class adhered strictly to every procedural phase of Discovery Learning, learning remained largely confined to passive, classroom-based theoretical activities (Kapur, 2016). In contrast, the Flipped Classroom model effectively restructured synchronous instructional time. These findings support and extend existing empirical literature (Hew et al., 2021; Stagg et al., 2025), confirming that shifting direct instruction to asynchronous preparation vacates in-class time for interactive, hands-on specimen analysis. Ultimately, this demonstrates that the cognitive quality of interactive synchronous tasks plays a far more decisive role in advancing biodiversity literacy than mere procedural compliance in traditional settings.

To address the practical issues observed during the pre-class phase and refine future implementations, targeted instructional adjustments were made. Instructors provided downloadable digital content via the school network prior to dismissal, securing equal access despite home internet constraint (Zainuddin & Halili, 2016). Additionally, applying micro-learning principles by maintaining video lengths under five minutes helped streamline cognitive processing (Fidan, 2023). Under Cognitive Load Theory, concise video media minimizes extraneous mental effort and prevents working memory overload during independent study (Noetel et al., 2021). By combining offline media preloading with brief microlearning units, this study provides a practical framework for delivering flipped botanical instruction within resource constrained or digitally diverse school settings.

Biodiversity literacy

Students' biodiversity literacy skills were assessed using pretest and posttest measures, with overall learning progress quantified through the Normalized Gain (N-Gain) metric. The mean scores and N-Gain categories for both the experimental and control classes are summarized in Table 6.

Table 6. N-Gain results of biodiversity literacy skills in the experimental and control classes

Class	Average Value			Category
	Pretest	Posttest	N-Gain	
Experiment	37	62,9	0,51	Medium
Control	37	50,9	0,28	Low

As shown in Table 6, both cohorts shared an identical baseline pretest average of 37, confirming initial equivalence in foundational knowledge. Following the intervention, the experimental group utilizing the Flipped Classroom model with localized Pteridophyte worksheets achieved a posttest score of 62.9, yielding a medium N-Gain of 0.51. Conversely, the control group taught via Discovery Learning recorded a posttest score of 50.9, resulting in a low N-Gain of 0.28. Within this instructional design, the contextualized fern worksheets served as an essential bridge connecting pre-class asynchronous study to hands-on classroom tasks, facilitating student learning progression (Förster et al., 2022; Ridlo et al., 2022). Grounded in the Cognitive Theory of Multimedia Learning (CTML), combining digital pre-class resources with structured visual worksheets optimizes dual-channel processing across visual and verbal modalities during concept acquisition (Mayer, 2021). This dual-coding mechanism supports the formation of robust mental models for complex botanical concepts, leading to superior learning gains compared to unimodal instruction (Fiorella et al., 2020). To evaluates the mean improvement across specific biodiversity literacy indicators, additional analyses were performed, with detailed results for both groups illustrated in Figure 3.

The indicator for applying biodiversity concepts occupied a middle position, yielding an N-Gain score of 0,39 (medium category) for the experimental class, whereas the control class trailed in the low category with an N-Gain score of 0,25. In the experimental class, independent student exploration during the pre-class phase established a solid cognitive foundation. Students have more time to digest abstract concepts, such as the mutualistic symbiosis between *Azolla pinnata* as a nitrogen provider and *Asplenium nidus* as a microhabitat former, before being verified in class. This structured integration of independent materials aligns with the opinions of Jartitngarm (2025) and Oktaviana and Leksono et al. (2015), who stated that pre-class contextual learning effectively stimulates students' readiness for active thinking. Conversely, in the control class using Discovery Learning, these systemic ecological concepts often led students astray. This condition contrasts with the control class, where the lack of prior information led students to experience cognitive overload, resulting in superficial analysis (Sweller, 2023). From a Constructivist perspective, pre-class preparation establishes an initial mental schema, enabling students to seamlessly assimilate complex ecological relationships during face-to-face sessions rather than experiencing conceptual disorientation (McLean et al., 2016)

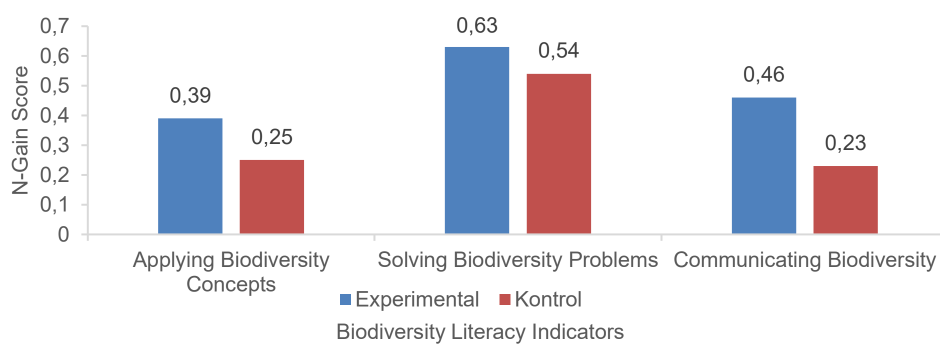

Figure 3. Average increase per biodiversity literacy indicator

Meanwhile, for the indicator of solving biodiversity problems, the experimental group recorded the largest increase, with an N-Gain of 0.63 (medium), while the control group recorded an N-Gain of 0.54 (medium). This achievement, which was in the moderate category, demonstrates that contextualizing biodiversity material through real case studies in the Mount Masigit Kareumbi area is highly effective in stimulating students' critical thinking in both classes. In the experimental class, the higher N-Gain advantage was achieved thanks to the time efficiency of the Flipped Classroom model, where the transfer of theoretical burdens outside the classroom provides a complete face-to-face space to practice higher-order thinking skills through problem-solving discussions (such as the cultivation zoning of *Diplazium esculentum* and saving *Selaginella doederleinii* colonies). This active classroom conditioning encourages students to formulate solutions grounded in empirical evidence. This is in line with the findings of Thai et al. (2017) and Oliván-Blázquez et al. (2023) who emphasized that eliminating one-way lectures in class provides students with the freedom to sharpen their application skills in solving environmental dilemmas concretely. Meanwhile, in the control class, the stimulation and problem identification stages of Discovery Learning were still able to engage student reasoning through the 5M scientific approach (the national framework for scientific learning), although not as optimally as in the experimental class due to the limited allocation of face-to-face time, which was still divided between delivering basic material and classroom activities. (Divjak et al., 2022).

In the indicator of communicating biodiversity, the experimental group achieved an N-Gain of 0.46 (medium), significantly outperforming the control group, which had an N-Gain of 0.23 (low). The relatively low achievement of both groups in the problem-solving aspect reflects the inherent complexity of correlating visual fern specimens with formal binomial nomenclature, such as distinguishing the morphological structures of *Platycerium bifurcatum* and *Nephrolepis cordifolia*. This difficulty illustrates a widespread pedagogical challenge in botanical education, where students' unfamiliarity with complex anatomical structures and Latinized terminology often hinders fluent scientific communication (Olatoye et al., 2026). In the experimental cohort, although contextualized worksheets provided necessary instructional scaffolding, mastering intricate taxonomic identification requires sustained engagement beyond short-term interventions (Achurra, 2022). Nevertheless, the Flipped Classroom model effectively mitigated these barriers by embedding dedicated evaluation and feedback sessions into the final phase of its instructional syntax. The sufficient discussion time allocated allowed each experimental group to present their analysis results, defend their scientific arguments, and receive interactive corrections on botanical terms. These guided communication skills, according to Pečiuliauskienė (2023), are effective in increasing students' scientific self-confidence. In contrast, in the control class with Discovery Learning, widespread time constraints led to the presentation and scientific terminology guidance stages at the end of class being rushed, so that students did not receive adequate feedback to improve the quality of their written and oral communication (Aldalur & Perez, 2023).

In addition to analyzing the increase descriptively, inferential statistical tests were also conducted on the N-Gain data to test the significance of differences in biodiversity literacy between groups. The results of this series of statistical tests are presented systematically in Table 7.

Table 7. Summary of statistical test results

Types of Statistical Tests	Tested Parameters	Sig. Value	Status
Prerequisite Test	Normality Test (Experiment)	0.374	Normally Distributed
	Normality Test (Control)	0.190	Normally Distributed
	Homogeneity Test	0.057	Homogeneous
Hypothesis Testing	Independent Sample t-Test	0.019	There is a significant difference
Effect Size	Cohen's d	0.392	Medium effect

Based on the summary of statistical test results in Table 7, all N-Gain value data are proven to meet the prerequisite assumption criteria for parametric statistical data analysis. The results of the normality test indicate that the distribution of data in the experimental group (Sig. 0.374) and the control group (Sig. 0.190) has a greater significance value than the alpha level of 0.05, thus categorized as normally distributed. This parametric conditioning is strengthened by the obtained significance value of the homogeneity of variance test of 0.057 (Sig. > 0.05), which confirms that the data for both groups are homogeneous. The fulfillment of normal data distribution standardization and uniform variance provides methodological certainty that the sample groups are in equal and objective initial conditions. Thus, the fulfillment of this prerequisite assumption provides a valid mathematical basis for continuing the inferential comparative analysis using the Independent Sample t-Test to ensure that the difference in final achievement is purely due to the learning model treatment and not to bias arising from the sample distribution inequality from the beginning.

Inferential hypothesis testing using an Independent Sample t-Test yielded a statistically significant difference between groups ($p = 0.019$, 2-tailed). Because the p-value fell below the standard significance

threshold ($p < 0.05$), the null hypothesis was rejected, confirming that biodiversity literacy gains differed significantly between the experimental and control cohorts. To assess the practical significance of this outcome, Cohen's d was calculated at 0.392, indicating a medium effect size. Reporting effect sizes alongside significance levels is essential in educational research to verify that the intervention produces a meaningful classroom impact rather than artifactual results driven by sample size (Dunkler et al., 2020). These findings align with existing literature demonstrating that student centered, active learning environments significantly enhance secondary science achievement compared to traditional instruction (Doğan et al., 2023; Oudbier et al., 2022; Turan, 2023). Furthermore, this moderate effect underscores how structured active learning fosters deeper cognitive engagement with biological content, thereby strengthening conceptual understanding (Yuretich et al., 2001).
Nevertheless, while the modified Flipped Classroom model supported by contextual worksheets produced significant improvements, overall post-intervention literacy skills reached the "Medium" performance category rather than the "High" tier. Pedagogically, this lacking achievement is due to the obstacle of partial student compliance during the independent phase before class (pre-class). The imbalance in prior knowledge among students due to non-academic constraints at home widens the gap in understanding when they enter the face-to-face session. As a result, the in-class deepening time, which should be fully devoted to evaluating a critical case study of ferns (Pteridophyte) in the Mount Masigit Kareumbi area, is still partially allocated to bridge students who are not yet ready to learn. This phenomenon confirms the theory that self-regulation and readiness for independent learning are the main internal determinants that limit the acceleration of students' cognitive gains in the flipped learning ecosystem (Akçayır & Akçayır, 2018; Silverajah et al., 2022).

Students response

A response questionnaire was administered to students in the experimental class to determine their responses during the Flipped Classroom learning process using the modified Student Worksheet. The average cumulative positive response of students to the Flipped Classroom model assisted by modified worksheet reached 93.9% (Very Good), reflecting a highly positive student reception of the instructional approach. The highest achievement was found in the conservation awareness indicator (99%) and the relevance of the material to local biodiversity (96%). This proves that integrating local fern content (Pteridophyte) from Mount Masigit Kareumbi is effective in reducing the abstraction of botanical material into a concrete and meaningful learning experience (Oktaviana et al., 2022). In addition, the high percentage of independent learning flexibility (94%) and group discussion effectiveness (93%) confirms the functional superiority of flipped learning. Pre-class conditioning provides students with full autonomy to construct prior knowledge, thereby making classroom group discussions more active, solution-oriented, and student-centered (Thai et al., 2017). From the framework of Self-Determination Theory, granting pre-class autonomy while contextualizing tasks with local biodiversity satisfies students' psychological needs for autonomy and relevance (Sointu et al., 2023). This alignment fosters intrinsic motivation, ultimately driving high satisfaction and active engagement throughout the flipped learning syntax (Mayer, 2021). Meanwhile, the visual appeal aspect recorded a score of 98%, followed by motivation for further learning (90%), and the usability of the worksheets (the lowest position at 87%). The percentage data for these responses are shown in Figure 4.

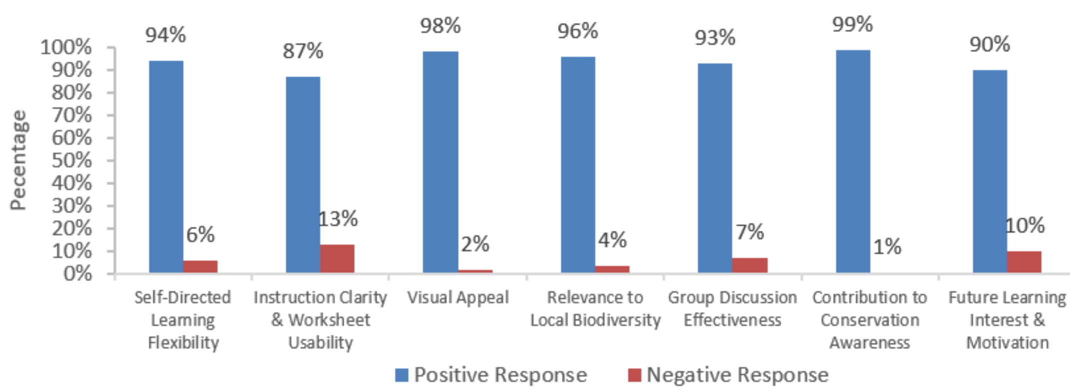

Figure 4. Summary of student response percentage results

Minor operational obstacles in the worksheets' usability correlated with students' cognitive load in adapting to independent learning and the complexity of the binomial nomenclature of ferns (Xin & Zhang, 2024). However, aesthetically pleasing visual media design interventions have been shown to mitigate symptoms of plant blindness and maintain student attention stability. Overall, the high level of positive perception across all dimensions demonstrates that aligning the flipped learning model with locally based media effectively fosters positive dispositions and students' readiness to learn science sustainably (Sointu et al., 2023). Under the Cognitive Theory of Multimedia Learning (CTML), incorporating visually appealing designs utilizes emotional design principles to cultivate positive affect during learning (Dunkler et al., 2020). Such affective engagement stimulates active cognitive processing when examining complex botanical structures, preventing visual habituation and maintaining student attention (Mayer, 2021).

Although field sampling was restricted to a specific zone within the study site, the identified Pteridophyte species provide a reliable representation of the regional flora. Expanding future field surveys across broader geographical boundaries could uncover greater fern taxonomic diversity. Nevertheless, the currently documented specimens serve as a reliable ecological baseline of the fern community in Gunung Masigit Kareumbi, providing sufficient morphological and taxonomic diversity to support the contextual learning objectives of the developed worksheets.

Conclusion

This study demonstrates that integrating the Flipped Classroom model with local Pteridophyte worksheets supports the enhancement of high school students' biodiversity literacy. By shifting theoretical preparation to asynchronous study, the model optimizes face-to-face classroom time for active, hands-on taxonomic analysis, thereby contributing to improved conceptual mastery and context-based biological literacy. Scientifically, this research establishes an integrative pedagogical framework that converts regional conservation assets into digital pre-class scaffolding to mitigate plant blindness and species literacy deficits. Practically, this approach provides educators with a scalable, context-driven model to foster higher-order biological reasoning and conservation awareness without overcomplicating in-class instruction. However, the scope of this study is still limited to the scope of the fern (Pteridophyte) material and was conducted in the context of one school with a specific sample, so the generalization of the results of this study is still limited. From a methodological standpoint, employing a quasi-experimental design with a modest sample size introduces potential selection bias, while the short intervention period limits the assessment of long-term knowledge retention. Additionally, extraneous variables such as variations in students' home digital access could not be fully controlled. Consequently, future research should expand sample sizes across broader geographical contexts, extend intervention durations, and apply advanced statistical techniques such as ANCOVA to control for baseline covariates effectively.

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Conflicts of Interest

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

Credit authorship contribution statement

S. Humairoh: Conceptualization, Methodology, Investigation, Data Curation, Formal analysis, Visualization, Writing – Original Draft; **M. Sholikha:** Conceptualization, Supervision, Writing – Review & Editing; **E. Paujiah:** Methodology, Supervision, Writing – Review & Editing; **F. E. Zamani:** Validation, Writing – Review & Editing.

Declaration of the use of AI

The authors utilized artificial intelligence tools strictly for language editing and grammatical refinement. All generated outputs were critically reviewed and revised by the authors, who maintain full accountability for the integrity and content of this publication.

Data availability statement

The data that support the findings of this study are available from the corresponding author, **[M.S]** upon reasonable request.

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