Jurnal Penelitian dan Pengkajian Ilmu Pendidikan: e-Saintika
https://journal-center.litpam.com/index.php/e-Saintika/index
July 2026 Vol. 10, No. 2
e-ISSN: 2615-6881
pp. 785-816

Kelimutu-Integrated Discovery Learning E-Module for Scientific Literacy and Self-Directed Learning in Biodiversity Education

* Maria Octaviani Inggrita Mesa, Suyitno Aloysius

Biology Education Master Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Sleman, Special Region of Yogyakarta, Indonesia.

*Corresponding Author e-mail: mariaoctaviani.2022@student.uny.ac.id

Received: February 2026; Revised: June 2026; Published: July 2026

Abstract

Scientific literacy and self-directed learning are important competencies in biology education that can be supported through contextual and systematically designed digital learning resources. This study aimed to develop and evaluate a discovery-learning e-module integrating the local biodiversity potential of Kelimutu National Park for Phase E biodiversity learning. The study employed the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model and was conducted from January to December 2025 at two high schools in Ende Regency. Feasibility was evaluated by one media and instructional-materials expert and one subject-matter expert, while practicality was assessed by two biology teachers and 35 Grade 10 students. Effectiveness was examined using a pretest-posttest nonequivalent control-group design involving 32 students in the experimental group and 30 students in the control group. Scientific literacy was measured using 10 valid and reliable essay items, whereas self-directed learning was assessed using a valid and reliable 20-item self-assessment instrument. Data were analyzed descriptively and using one-way MANOVA. The e-module was rated very feasible by both experts and very practical by teachers and students. The experimental group showed larger descriptive gains in scientific literacy (60.40 to 85.59) and self-directed learning (63.46 to 86.90) than the control group (50.83 to 59.70 and 56.66 to 66.93, respectively). The MANOVA showed a significant multivariate group difference, Pillai's Trace = .958, $F(2, 59) = 671.689$, $p < .001$. Follow-up tests also showed significant group differences in scientific literacy and self-directed learning, with large effect sizes. These findings support the educational potential of a Kelimutu-integrated discovery-learning e-module as a feasible, practical, and contextually meaningful digital resource for supporting scientific literacy and self-directed learning in biodiversity education.

Keywords: Biodiversity Education; Contextual Learning; Digital Flipbook; Local Biodiversity; Scientific Literacy; Self-Directed Learning

How to Cite: Mesa, M. O. I., & Aloysius, S. (2026). Kelimutu-Integrated Discovery Learning E-Module for Scientific Literacy and Self-Directed Learning in Biodiversity Education. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika, 10*(2), 785-816. https://doi.org/10.36312/e-saintika.v10i2.4606

10.36312/e-saintika.v10i2.4606

INTRODUCTION

Scientific literacy is a fundamental competency in biology education because it enables students to understand scientific information and apply scientific knowledge when addressing problems in everyday life (Niate & Paidi, 2025). Broadly, scientific literacy involves the ability to use scientific knowledge and evidence to identify problems, explain phenomena, evaluate information, and draw evidence-based conclusions about the natural world and changes resulting from human activities (Bórquez-Sánchez, 2025; Sjöström, 2025). These competencies are important because scientific understanding becomes meaningful when students can use it to reason about problems and make informed decisions (Niate & Paidi, 2025). Therefore, scientifically literate students should not only understand biological concepts but also be able to apply scientific knowledge and process skills to analyze problems, evaluate evidence, and justify decisions scientifically.

Scientific literacy is closely related to students' capacity to manage their own learning. Self-directed learning enables students to take greater responsibility for identifying learning needs, selecting appropriate resources and strategies, monitoring their progress, and evaluating whether their learning goals have been achieved (Alfi et al., 2024; Novalia et al., 2025). Importantly, self-directed learning does not imply that students learn without guidance; rather, learner responsibility needs to be deliberately structured and supported through appropriate instructional activities (Kaya et al., 2026). Students with stronger self-directed learning are more likely to set goals, manage time, seek relevant information, reflect on their progress, and adjust learning strategies when necessary (Novalia et al., 2025). Such independence also provides opportunities for students to broaden their knowledge, analyze complex problems systematically, explore alternative solutions, and develop the capacity to apply knowledge independently in authentic situations (Shaydulloyevich, 2025). Thus, scientific literacy provides students with competencies for reasoning with scientific information, whereas self-directed learning supports their capacity to independently develop and apply those competencies.

Despite the importance of these competencies, evidence indicates persistent challenges in students' scientific literacy and self-directed learning in Indonesia. At the national level, PISA 2022 reported that only 34% of Indonesian 15-year-old students attained at least Level 2 proficiency in science, compared with an OECD average of 76% (OECD, 2023). This broader pattern is consistent with studies reporting relatively low scientific literacy among high school students in Sleman Regency (Budiastuti & Mercuriani, 2025), secondary-school and university students in Indonesia (Ayu et al., 2025; S. Sidauruk et al., 2025), and junior high school students in Yogyakarta City and Wonosobo (Nurohman & Fikri, 2025; Wisdayana et al., 2025). Challenges have likewise been reported for students' learning independence or self-directed learning across different educational settings, including elementary-school students in Klaten Regency (Anayanti & Zainuddin, 2025), high-school students in physics learning in East Lombok (Zahara et al., 2025), junior-high-school students in Flores following the pandemic (Wege et al., 2022), students from different specialization classes in Central Timor (Sele et al., 2023), and vocational-school students (Setyaningsih et al., 2023). Taken together, these findings suggest that strengthening scientific literacy and students' capacity to learn independently remains an important challenge across Indonesian educational contexts.

A similar challenge was identified through the needs analysis conducted in public and private high schools in Ende Regency. Interviews with biology teachers indicated that some students had difficulty answering essay questions involving real-world problems, and many students' daily assessment scores remained below the Minimum Proficiency Criteria. Teachers also reported limited self-directed learning among Grade 10 students, as reflected, for example, in delays in completing assignments. Classroom observations reinforced these findings: some students remained highly dependent on teachers or peers when completing learning activities and assignments. This dependence made it difficult for them to independently identify learning needs, establish learning goals, select appropriate strategies, and locate relevant learning resources. These conditions are particularly important in biology education, where students are expected not only to understand concepts but also to connect them with biological phenomena and problems encountered in their surroundings.

Addressing these challenges requires teaching materials that are responsive to students' characteristics, provide meaningful contexts for learning, and facilitate more active and independent engagement. Technology-supported instructional resources provide opportunities to develop such learning environments while supporting competencies required in contemporary education (Syahira et al., 2025). Learning materials should therefore be designed according to students' learning needs and characteristics rather than functioning merely as generic sources of content (Bahi & Aloysius, 2025; Pantiwati et al., 2025; T. Sidauruk et al., 2025). However, the needs analysis in public and private high schools in Ende Regency showed that biology teachers still relied primarily on textbooks and workbooks provided by the Ministry of Education, materials obtained from publishers or the internet, and supplementary PowerPoint presentations. Teachers also reported limited experience in independently developing instructional materials tailored to their students and local learning contexts. Consequently, there is a need for teaching materials that combine digital accessibility with contextual biological content and activities that promote greater learner participation and independence.

Electronic modules (e-modules) provide one potential response to this need. E-modules allow learning materials to be organized digitally and can facilitate more flexible and engaging delivery of biological content (Niate & Paidi, 2025; Salim Putra et al., 2025). Unlike materials dominated by printed text, e-modules can integrate multimedia components such as images, audio, and video to represent biological phenomena more dynamically (T. Sidauruk et al., 2025). Their digital format also enables students to access learning materials more flexibly and to engage with learning activities independently (Yerimadesi et al., 2023). Previous studies have reported that appropriately designed e-modules can support conceptual understanding and problem-solving (Pantiwati et al., 2025), learning outcomes, motivation, and self-directed learning (T. Sidauruk et al., 2025), as well as students' scientific literacy (Prihatiningtyas et al., 2025; Susilawati et al., 2025). However, providing an electronic resource alone does not guarantee meaningful or independent learning; its pedagogical design remains critical.

Indeed, the effective use of e-modules may be constrained when students have difficulty regulating their own learning or when digital materials provide insufficient interaction and instructional feedback (Utama & Zulyusri, 2022). Therefore, e-modules need to be organized around a learning model that actively guides students through processes of inquiry, evidence gathering, analysis, and knowledge construction. Discovery learning offers such a framework because students are encouraged to actively discover concepts rather than receiving them only in their final form (Utaminingsih et al., 2022). Through discovery-oriented activities, students can interpret information, classify observations, formulate hypotheses, explain phenomena, make measurements, and construct conclusions as part of the problem-solving process (Hopipah et al., 2025). Previous studies have also associated discovery learning with improvements in science process skills and learning outcomes (Khairani & Prodjosantoso, 2023), problem-solving ability (Hariyanto et al., 2023), critical and metacognitive thinking (Pratama et al., 2024), scientific literacy and learning outcomes (Berliana et al., 2023), and students' self-directed learning (Mahdi et al., 2023). These characteristics make discovery learning particularly relevant for an e-module intended to develop scientific literacy and self-directed learning simultaneously.

The instructional relevance of discovery learning can be further strengthened when the phenomena explored by students originate from contexts that are meaningful and recognizable to them. Kelimutu National Park provides such a context because its distinctive natural environment, including the Three-Colored Lakes and its biodiversity, offers authentic biological resources that can be connected with biodiversity concepts. In the proposed e-module, these local resources are used as contextual stimuli and sources of information through which students observe biological phenomena, identify problems, explore information, analyze evidence, and formulate conclusions within the stages of discovery learning. Previous research suggests that integrating local resources into learning can support scientific literacy (Fitrianawati & Noerazizah, 2025), self-directed learning (Widyaningrum & Prihastari, 2023), critical thinking (Fitrianawati & Noerazizah, 2025), creative thinking (Sari et al., 2025), and learning outcomes (Pamungkas et al., 2023). Contextualizing learning through local resources can also make concepts more relevant and meaningful because students can connect academic content with phenomena in their surrounding environment (Sayangan, 2024). More broadly, the educational integration of local contexts and community knowledge can also provide opportunities for students to appreciate the cultural and social dimensions associated with their environment and heritage (Homsombat, 2025; Judijanto et al., 2024).

Although previous studies have demonstrated the educational potential of e-modules, discovery learning, and locally contextualized learning, an important gap remains in how these components are combined. The studies reviewed above have largely examined these elements separately or in different combinations, while limited attention has been given to a device-flexible digital resource that integrates the discovery-learning sequence with the biodiversity context of Kelimutu National Park and simultaneously targets scientific literacy and self-directed learning. To address this gap, the present study developed the e-module as a flipbook rather than as a device-specific application, allowing the learning resource to be accessed across a wider range of devices and operating systems. More importantly, Kelimutu National Park is incorporated not merely as illustrative content but as a contextual learning resource embedded within discovery activities through which students investigate biodiversity-related phenomena and construct scientific understanding. Thus, the novelty of this study lies in the integration of discovery learning, Kelimutu National Park biodiversity, and flexible flipbook technology within a single e-module designed to support two complementary learning outcomes: scientific literacy and self-directed learning. Accordingly, this study aimed to develop and evaluate a discovery-learning e-module integrating the local potential of Kelimutu National Park that is feasible, practical, and effective for Phase E high-school biodiversity learning. The effectiveness hypothesis was that students learning with the developed e-module would demonstrate higher post-intervention scientific literacy and self-directed learning than students receiving the comparison instruction.

METHOD

Research Design and Setting

This study employed a research-and-development design using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model to develop and evaluate a discovery-learning e-module integrating the local potential of Kelimutu National Park. The e-module was designed for Phase E biodiversity learning, with an emphasis on plant diversity, and was evaluated in terms of feasibility, practicality, and effectiveness in supporting students' scientific literacy and self-directed learning. The study was conducted from January to December 2025 at Public High School 1 Ende and St. Thomas Morus High School in Ende Regency.

The study consisted of two interconnected components. The first involved the development and formative evaluation of the e-module through the ADDIE stages. The second involved an effectiveness evaluation using a pretest-posttest nonequivalent control-group design. Figure 1 presents the complete ADDIE-based development procedure, whereas Table 3 presents the quasi-experimental design used during the implementation phase.

Participants and Study Groups

Participants were involved at three evaluation stages: feasibility, practicality, and effectiveness testing. Table 1 summarizes the qualifications and composition of the experts, teachers, and students involved at each stage.

The feasibility evaluation involved two experts from Yogyakarta State University: one lecturer specializing in biology education, who evaluated the media and instructional-material aspects of the e-module, and one biology lecturer with expertise in botany, who evaluated the subject-matter content.

The practicality evaluation involved two biology teachers and 35 Grade 10 students. One teacher was from Public High School 1 Ende and one was from St. Thomas Morus High School. The 35 students participating in the practicality evaluation were from St. Thomas Morus High School and had previously studied biodiversity. Their prior exposure to the topic enabled them to evaluate the clarity, usability, and relevance of the developed learning material.

Table 1. Criteria for evaluating the feasibility, practicality, and effectiveness of e-modules

Expert/Practitioner	Qualifications	Participants
Media and instructional-materials specialist	1. Minimum qualification: Master's degree and lecturer position, or Doctorate/Ph.D. 2. Field of expertise: media and instructional materials or learning technology	1 lecturer in Biology Education, Yogyakarta State University
Subject-matter expert	1. Minimum qualification: Master's degree and lecturer position, or Doctorate/Ph.D. 2. Field of expertise: Botany	1 lecturer in Biology, Yogyakarta State University
Teacher	1. Minimum Bachelor's degree in Biology Education, preferably with a teaching certificate 2. At least 5 years of teaching experience 3. At least 3 years of experience teaching Grade 10 students	1 biology teacher from Public High School 1 Ende and 1 biology teacher from St. Thomas Morus High School
Student	Had already studied biodiversity	35 Grade 10 students from St. Thomas Morus High School

Expert/Practitioner	Qualifications	Participants
Student	Had not yet studied biodiversity	32 students from Class X.1 and 30 students from Class X.2 at Public High School 1 Ende

The effectiveness evaluation was conducted at Public High School 1 Ende and involved 62 Grade 10 students who had not yet studied the targeted biodiversity material. The study used random sampling. Class X.1, consisting of 32 students, served as the experimental group, whereas Class X.2, consisting of 30 students, served as the control group. Table 2 presents the gender and age distribution of students in both groups. Most participants in both groups were younger than 17 years.

Table 2. Student demographics for the e-module effectiveness test

Group	Characteristic	Category	N
Experimental	Gender	Female	20
	Gender	Male	12
	Age	<17 years old	29
	Age	>17 years old	3
Control	Gender	Female	19
	Gender	Male	11
	Age	<17 years old	29
	Age	>17 years old	1

Effectiveness-Test Design

The effectiveness of the developed e-module was examined using a pretest-posttest nonequivalent control-group design. Both groups completed assessments of scientific literacy and self-directed learning before and after instruction. The experimental group learned using the discovery-learning e-module integrating the local resources of Kelimutu National Park, whereas the control group learned using the teacher learning module. The complete effectiveness-test design is presented in Table 3 (Creswell & Plano Clark, 2007).

Table 3. Design of an e-module effectiveness test

Group	Pre-test	Treatment	Post-test
Experimental	Scientific literacy and self-directed learning	Discovery-learning e-module integrated with local resources	Scientific literacy and self-directed learning
Control	Scientific literacy and self-directed learning	Teacher learning module	Scientific literacy and self-directed learning

E-Module Development Procedure

The development procedure followed the five ADDIE stages: analysis, design, development, implementation, and evaluation. Figure 1 summarizes the activities conducted at each stage and illustrates the relationship among these stages.

During the analysis stage, the researchers identified the learning needs of teachers and students through interviews and classroom observations at Public High School 1 Ende and St. Thomas Morus High School. The needs analysis examined the instructional resources used in biology learning, students' learning characteristics, and difficulties associated with scientific literacy and self-directed learning. The findings provided the empirical basis for preparing the e-module storyboard and determining its instructional features.

During the design stage, the researchers analyzed relevant local resources from Kelimutu National Park and aligned them with the biodiversity learning objectives. This stage included designing the e-module structure, mapping discovery-learning activities to the intended learning outcomes, preparing feasibility and practicality assessment instruments, and developing instruments for measuring scientific literacy and self-directed learning.

During the development stage, the initial e-module prototype was evaluated by the media and instructional-materials expert and the subject-matter expert whose qualifications are described in Table 1. The product was subsequently revised according to the experts' recommendations before being evaluated by practitioners. Practicality evaluation involved the two biology teachers and 35 students specified in Table 1. During the same stage, the scientific-literacy and self-directed-learning instruments were subjected to expert evaluation and pilot testing at St. Thomas Morus High School. Instruments that met the validity and reliability requirements were subsequently used in the effectiveness evaluation.

During the implementation stage, the developed e-module was implemented in the experimental group at Public High School 1 Ende according to the quasi-experimental design presented in Table 3. The characteristics of the participating experimental and control groups are reported in Table 2. Finally, evaluation was conducted throughout the ADDIE process, allowing information obtained at each stage to inform revisions and subsequent development activities.

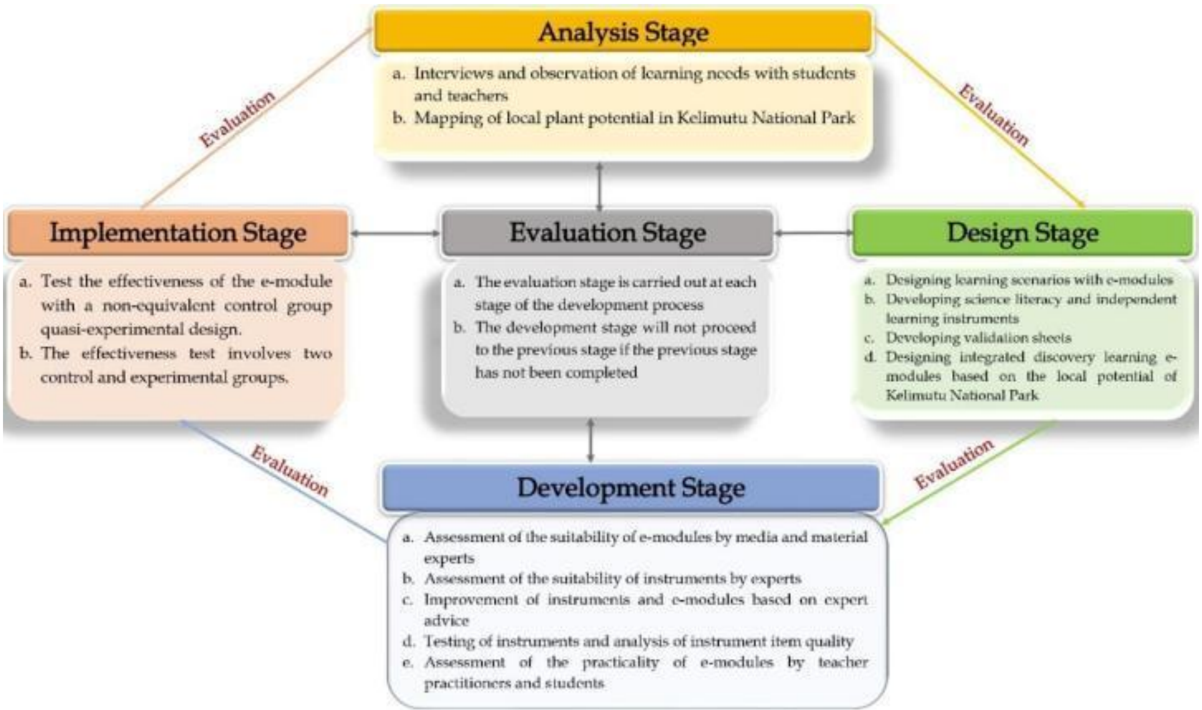


Figure 1. Procedures for developing e-modules using the ADDIE model (Branch, 2010)

Data Collection and Research Instruments

Data collection addressed the three product-evaluation criteria: feasibility, practicality, and effectiveness. Feasibility and practicality data were collected using product-evaluation sheets, whereas effectiveness data comprised students' scientific-literacy and self-directed-learning scores.

Feasibility and Practicality Instruments

The feasibility instruments were completed by the media and instructional-materials expert and the subject-matter expert. The practicality instruments were completed by biology teachers and students after examining or using the e-module. Both instruments employed a four-point Likert-type rating scale: 1 = very poor, 2 = poor, 3 = good, and 4 = very good. The resulting scores were used to evaluate the suitability and usability of the developed product.

Scientific-Literacy Instrument

Scientific literacy was measured using 10 researcher-developed essay questions. The instrument assessed local, global, and personal contexts; the competencies of explaining phenomena scientifically, evaluating and designing scientific investigations, and interpreting data and evidence scientifically; and content, procedural, and epistemic knowledge. Student responses were scored using a rubric ranging from 1 to 4. The indicators, item allocation, and item-validity coefficients are presented in Table 4.

Self-Directed-Learning Instrument

Self-directed learning was measured using a researcher-developed 20-item self-assessment instrument. The instrument assessed five dimensions: independence from others, self-initiative, self-discipline, personal responsibility, and confidence in one's own abilities. Students responded using a four-point scale: 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree. Table 4 presents the distribution and validity coefficients of the 20 items.

Instrument Validity and Reliability

Before being administered in the effectiveness study, the scientific-literacy and self-directed-learning instruments were reviewed by a biology-education expert from Yogyakarta State University. Following expert review, both instruments were pilot-tested with 60 Grade 10 students at St. Thomas Morus High School to examine item quality, validity, and reliability.

Item validity was analyzed using the Pearson product-moment correlation in IBM SPSS Statistics 25. Following the criterion used in the original instrument-development procedure, an item was considered valid when its calculated correlation coefficient exceeded the critical correlation coefficient (Sari et al., 2024). The critical value applied in the study was r_table = 0.2144, based on N - 2 = 58 degrees of freedom. Reliability was assessed using Cronbach's alpha, with coefficients above .70 regarded as indicating adequate reliability for research use (Sari et al., 2024).

Table 4. Results of the validity and reliability tests of the research instruments

Instrument	Indicator	Item	Calculated r	Description
Scientific literacy	Local context	Item 1	.874	Valid
	Global issues	Item 2	.711	Valid
	Personal issues	Item 3	.914	Valid
	Explaining phenomena scientifically	Item 4	.514	Valid
	Evaluating and designing scientific investigations	Item 5	.654	Valid
		Item 6	.745	Valid
	Interpreting data and evidence scientifically	Item 7	.532	Valid
	Content knowledge	Item 8	.402	Valid

Instrument	Indicator	Item	Calculated r	Description
	Procedural knowledge	Item 9	.786	Valid
	Epistemic knowledge	Item 10	.715	Valid
Self-directed learning	Not dependent on others	Item 1	.774	Valid
		Item 2	.811	Valid
		Item 3	.941	Valid
		Item 4	.725	Valid
		Item 5	.654	Valid
		Item 6	.745	Valid
		Item 7	.652	Valid
	Self-initiative	Item 8	.602	Valid
		Item 9	.654	Valid
		Item 10	.866	Valid
		Item 11	.715	Valid
	Self-discipline	Item 12	.891	Valid
		Item 13	.725	Valid
	Taking responsibility for oneself	Item 14	.756	Valid
		Item 15	.546	Valid
		Item 16	.541	Valid
	Believing in one's own abilities	Item 17	.642	Valid
		Item 18	.705	Valid
		Item 19	.711	Valid
		Item 20	.874	Valid

As shown in Table 4, all 10 scientific-literacy items met the item-validity criterion, with calculated correlations ranging from .402 to .914. The complete scientific-literacy instrument yielded a Cronbach's alpha coefficient of .741. All 20 self-directed-learning items were also classified as valid, with calculated correlations ranging from .541 to .941, and the complete instrument yielded a Cronbach's alpha coefficient of .845. Thus, both instruments met the validity and reliability criteria established for their use in the effectiveness evaluation.

Ethical Considerations

Most students participating in the effectiveness evaluation were younger than 17 years, as shown in Table 2. Therefore, procedures for communicating the study to students and their parents were implemented with reference to ethical guidance for research involving children (Graham et al., 2013). Before data collection, the classroom teacher, in collaboration with the researcher, explained the research plan and learning activities to the participating students so that they were aware of what their participation involved. Parents were also informed through the class WhatsApp communication group, and students were asked to confirm whether their parents had granted permission for their participation. The research activities were conducted during regular class hours and did not require additional instructional time or disrupt the normal learning schedule.

Data Analysis

Feasibility and Practicality Analysis

Feasibility and practicality scores were analyzed descriptively by calculating the mean score for each evaluated aspect. The product was expected to achieve at least the 'good' category for each aspect, and revisions were implemented in response to expert and practitioner recommendations. Table 5 presents the score ranges used to interpret feasibility and practicality ratings.

Table 5. Criteria for deciding on product feasibility and practicality

Score range	Criteria	Decision
3.25 <= M <= 4.00	Excellent	Very feasible/very practical
2.50 <= M < 3.25	Good	Feasible/practical
1.75 <= M < 2.50	Poor	Less feasible/practical
1.00 <= M < 1.75	Very poor	Not feasible/not practical

Descriptive and Inferential Analysis of Effectiveness

Scientific-literacy and self-directed-learning scores were first analyzed descriptively using the mean, median, standard deviation, minimum, maximum, and range to characterize students' pretest and posttest performance in each group. Inferential analysis was then conducted using a one-way multivariate analysis of variance (MANOVA), with instructional group as the independent variable and scientific literacy and self-directed learning as the dependent variables. All inferential analyses were performed using IBM SPSS Statistics 25.

Before conducting MANOVA, the relevant multivariate assumptions were examined. Multivariate normality was assessed using Mahalanobis-distance and chi-square values, whereas homogeneity of the covariance matrices was examined using Box's M test. MANOVA was conducted after these assumptions were considered satisfied. Table 6 presents the decision rule for interpreting the omnibus multivariate test. A statistically significant MANOVA indicates a multivariate difference between the experimental and control groups across the combined dependent variables; it does not, by itself, establish that each dependent variable differs individually. Therefore, significant multivariate results were followed by between-subjects tests for scientific literacy and self-directed learning separately.

Table 6. Decision-making criteria for the one-way MANOVA test

Criteria	Decision
p < .05	There is a statistically significant multivariate difference between the experimental and control groups across the combined dependent variables of scientific literacy and self-directed learning. Follow-up between-subjects tests are required to determine which dependent variable(s) differ significantly.
p >= .05	There is insufficient evidence of a statistically significant multivariate difference between the experimental and control groups across the combined dependent variables.

For the follow-up between-subjects tests, a significance level of $p < .05$ was interpreted as evidence of a statistically significant group difference for the respective dependent variable. Statistical significance was supplemented with an effect-size estimate using partial eta squared (ηp^2) to describe the magnitude of the group effect. Effect-size reporting was retained as part of the analytical framework used in educational research (Juandi et al., 2021). However, because the statistic reported in this study is partial eta squared, interpretation must account for its 0-1 scale and should not use thresholds intended for standardized mean-difference statistics (Richardson, 2011; Lakens, 2013). For the present single-factor between-subjects follow-up analyses, the conventional reference values shown in Table 7 were used as descriptive benchmarks rather than rigid substantive cutoffs.

Table 7. Classification of effect-size test results

Partial eta squared (ηp^2)	Interpretation
< .01	Negligible
.01 to < .06	Small
.06 to < .14	Moderate
>= .14	Large

Accordingly, the effectiveness analysis considered three complementary forms of evidence: descriptive changes from pretest to posttest, the omnibus multivariate comparison of scientific literacy and self-directed learning, and the follow-up between-subjects tests together with their partial eta-squared effect sizes.

RESULTS AND DISCUSSION

Design and Instructional Alignment of the Discovery-Learning E-Module

The developed e-module integrates the discovery-learning sequence with the local biodiversity context of Kelimutu National Park for Phase E biology learning, particularly plant diversity. Figure 2 illustrates representative components of the e-module, including the cover, biodiversity learning materials, and contextual information related to Kelimutu National Park. The product was developed as a digital flipbook that can be accessed through Android and iOS smartphones as well as computers running Windows or macOS. The e-module was implemented over three learning sessions and included contextual readings, worksheets, multimedia resources, learning materials, assessment activities, and opportunities for classroom discussion and feedback.

Figure 2. Design of an e-module on discovery learning that integrates the local potential of Kelimutu National Park

The instructional structure was designed to align each discovery-learning stage with indicators of scientific literacy and self-directed learning. Table 8 summarizes this alignment while also presenting the principal activities and Kelimutu-based learning resources embedded in each session. During the first session, students encountered biodiversity information and local phenomena from Kelimutu National Park as contextual stimuli. These activities addressed scientific-literacy indicators related to local, global, and personal contexts and content knowledge while encouraging students to engage with the learning materials independently. In the problem-identification stage, students answered questions derived from the contextual readings, thereby engaging in explaining scientific phenomena and epistemic reasoning while developing self-initiative.

During the second session, students collected information from the e-module and other learning resources and subsequently organized and analyzed the information in tables or diagrams. These activities targeted the competencies of evaluating and designing scientific investigations, procedural knowledge, and interpreting scientific data and evidence. The activities were also designed to foster self-discipline and confidence in students' ability to complete learning tasks. During the third session, students verified their findings through classroom presentations and peer responses before drawing conclusions in the form of a mind map. These stages addressed scientific interpretation and explanation while requiring students to take responsibility for their own conclusions.

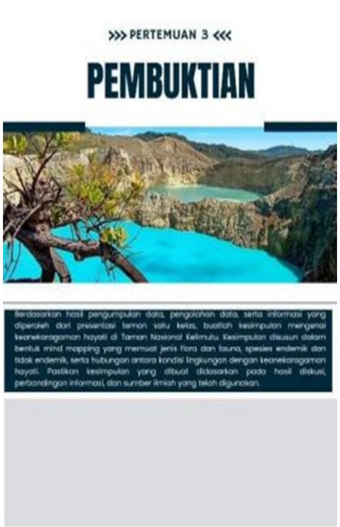
Table 8. Alignment of discovery-learning stages, Kelimutu-based learning activities, scientific-literacy indicators, and self-directed-learning indicators

Meeting or Section	**Discovery-learning stage or e-module component**	**Kelimutu-based learning activity/content**	**Scientific-literacy indicator**	**Self-directed-learning indicator**
Introductory section	Orientation and instructions  PENDAHULUAN A. Deskripsi Singkat E-modul ini membahas tentang tumbuhan paku (Pteridophyta) yang berada di taman Nasonal Kelimutu yang merupakan kelompok tumbuhan berpembuluh namun belum menghasilkan biji. Model pembelajaran yang di gunakan menggunakan metode Discovery Learning. B. Tujuan Pembelajaran Setelah mempelajari modul ini, peserta didik diharapkan mampu: • Menjelaskan ciri-ciri umum tumbuhan paku. • Mengidentifikasi struktur tubuh tumbuhan paku. • Menjelaskan siklus hidup (metagenesis) tumbuhan paku. • Mengklasifikasikan jenis-jenis tumbuhan paku • Mendeskripsikan peranan tumbuhan paku dalam kehidupan sehari-hari dan lingkungan • Mengidentifikasi jenis-jenis tanaman paku di Taman Nasional Kelimutu. • Memberikan solusi terhadap masalah lingkungan yang berkaitan dengan tanaman paku, misalnya menjaga habitat atau membuat program konservasi di Taman nasional Kelimutu .	Description of the e-module, learning objectives, and instructions for independent use	-	Supports independent navigation of learning activities
1	Stimulation  TAMAN NASIONAL KELIMUTU: SURGA KEANEKARAGAMAN HAYATI NUSA TENGGARA "TAMAN NASIONAL KELIMUTU" "AKTIVITAS GEOKIMIA DI KAWASAN VULKANIK"	Contextual reading on the biodiversity and natural phenomena of Kelimutu National Park	Local, global, and personal issues; content knowledge	Not dependent on others

Meeting or Section	Discovery-learning stage or e-module component	Kelimutu-based learning activity/content	Scientific-literacy indicator	Self-directed-learning indicator
1	Problem identification 	Students answer questions based on the Kelimutu National Park contextual text	Explaining phenomena scientifically; epistemic knowledge	Self-initiative
1	Learning materials 	Biodiversity concepts are connected with the local potential of Kelimutu National Park	Content knowledge	Independent study
2	Data collection 	Students search e-modules, books, articles, and internet sources for information related to flora and fauna in Kelimutu National Park	Evaluating and designing scientific investigations; procedural knowledge	Self-discipline

<table>
<tr><th>Meeting or Section</th><th>Discovery-learning stage or e-module component</th><th>Kelimutu-based learning activity/content</th><th>Scientific-literacy indicator</th><th>Self-directed-learning indicator</th></tr>
<tr><td>2</td><td>Data processing

</td><td>Students organize, categorize, compare, and analyze collected information using tables or diagrams</td><td>Interpreting data and evidence scientifically</td><td>Believing in one's own abilities</td></tr>
<tr><td>2</td><td>Learning materials

</td><td>Students independently review and summarize the material presented in the second session</td><td>-</td><td>Independent learning</td></tr>
<tr><td>3</td><td>Verification

</td><td>Students present investigation results, respond to peers, and identify differences among findings</td><td>Interpreting data and evidence scientifically</td><td>-</td></tr>
</table>

Meeting or Section	Discovery-learning stage or e-module component	Kelimutu-based learning activity/content	Scientific-literacy indicator	Self-directed-learning indicator
3	Drawing conclusions 	Students formulate conclusions and organize the findings into a mind map	Explaining phenomena scientifically	Taking responsibility for oneself
3	Learning materials 	Biodiversity material is reviewed to reinforce concepts covered during the learning sequence	-	Independent consolidation of learning
Local-potential study	Contextual learning resource 	Images and videos of biodiversity, including higher plants and ferns documented in Kelimutu National Park	Application of biodiversity knowledge in a local context	Supports contextual independent exploration

As summarized in Table 8, Kelimutu National Park was incorporated not only as illustrative material but also as a contextual source for observation, information gathering, analysis, verification, and conclusion formation. Higher plants and ferns documented in previous local studies were represented through images and videos, allowing students to investigate local biodiversity without requiring direct access to the national park.

Feasibility and Expert-Based Product Revision

The e-module underwent feasibility evaluation by a media and instructional-materials expert and a subject-matter expert before being evaluated by teachers and students. Table 9 combines the original feasibility assessments and the principal product revision recommended by the experts.

The media and instructional-materials expert assigned an overall mean score of 3.7, corresponding to the 'very feasible' category. The highest scores were obtained for language, graphic design, and usability (3.8 each), whereas presentation received a score of 3.4. The subject-matter expert assigned an overall mean score of 3.5, also corresponding to the 'very feasible' category. Material accuracy received the highest score (3.8), followed by learning alignment (3.6), didactics (3.4), and construction (3.4).

Table 9. Combined results of expert feasibility assessment and product revision

Evaluator	Assessment aspect	Mean score	Overall mean	Decision
Media and instructional-materials expert	Competency alignment	3.6	3.7	Very feasible
	Language	3.8		
	Presentation	3.4		
	Graphic design	3.8		
	Usability	3.8		
Subject-matter expert	Learning	3.6	3.5	Very feasible
	Material accuracy	3.8		
	Didactics	3.4		
	Construction	3.4		

Expert-requested revision: The product title was changed from 'teaching module' to 'e-module' to ensure that the terminology accurately reflected the digital instructional product being developed.

As shown in Table 9, both experts rated the product as very feasible. Nevertheless, the expert recommendations were incorporated before the practicality evaluation, including revision of the product terminology displayed on the module cover.

Practicality of the E-Module

Following expert revision, the e-module was evaluated for practicality by two biology teachers and 35 Grade 10 students. Table 10 consolidates the practicality assessments originally reported separately for teachers and students.

Teacher 1 assigned an overall mean score of 3.7, whereas Teacher 2 assigned an overall mean score of 3.8. Both evaluations corresponded to the 'very practical' category. Competency alignment received the maximum score of 4.0 from both teachers. The student evaluation also produced an overall mean of 3.7, corresponding to the 'very practical' category. Students gave the highest score to the material aspect (4.0), followed by language (3.8), use/operation (3.6), and display (3.6).

Table 10. Combined results of teacher and student practicality assessments

Evaluator	Assessment aspect	Mean score	Overall mean	Decision
Teacher 1	Competency alignment	4.0	3.7	Very practical
	Materials	3.8		
	Use	3.6		
	Media	3.6		
Teacher 2	Competency alignment	4.0	3.8	Very practical

Evaluator	Assessment aspect	Mean score	Overall mean	Decision
	Materials	3.6		
	Use	3.8		
	Media	3.8		
Students	Materials	4.0	3.7	Very practical
	Language	3.8		
	Use/operation	3.6		
	Display	3.6		

The results presented in Table 10 indicate that both teachers and students considered the e-module practical for classroom use. The teacher evaluations particularly supported its alignment with instructional competencies, whereas the student evaluations indicated favorable perceptions of the learning materials, language, operation, and visual presentation.

Descriptive Outcomes for Scientific Literacy and Self-Directed Learning

Descriptive statistics for scientific literacy and self-directed learning are consolidated in Table 11. Both groups showed higher mean scores at posttest than at pretest; however, the magnitude of the observed increase was greater in the experimental group for both outcomes.

For scientific literacy, the experimental-group mean increased from 60.40 (SD = 4.46) at pretest to 85.59 (SD = 3.24) at posttest, corresponding to a mean increase of 25.19 points. In comparison, the control-group mean increased from 50.83 (SD = 5.81) to 59.70 (SD = 3.85), corresponding to an increase of 8.87 points.

A similar pattern was observed for self-directed learning. The experimental-group mean increased from 63.46 (SD = 2.83) to 86.90 (SD = 3.28), representing an increase of 23.44 points. The control-group mean increased from 56.66 (SD = 3.60) to 66.93 (SD = 3.85), corresponding to an increase of 10.27 points.

Table 11. Combined descriptive statistics for scientific literacy and self-directed learning

Outcome	Group	Pretest Mean (SD)	Posttest Mean (SD)	Mean gain	Median pretest -> posttest	Min-max pretest -> posttest
Scientific literacy	Experimental	60.40 (4.46)	85.59 (3.24)	25.19	61.00 -> 85.00	53-69 -> 81-93
	Control	50.83 (5.81)	59.70 (3.85)	8.87	52.00 -> 60.00	34-59 -> 52-65
Self-directed learning	Experimental	63.46 (2.83)	86.90 (3.28)	23.44	63.00 -> 87.00	58-69 -> 81-94
	Control	56.66 (3.60)	66.93 (3.85)	10.27	57.00 -> 67.00	50-63 -> 59-74

As shown in Table 11, the experimental group exhibited larger descriptive gains than the control group in both scientific literacy and self-directed learning. The table also shows that the experimental group had higher mean pretest scores than the control group on both variables. Therefore, the descriptive results indicate different starting levels between the groups in addition to the larger observed post-intervention gains in the experimental group.

Assumption Testing for Multivariate Analysis

Before conducting the MANOVA, multivariate normality and homogeneity of the covariance matrices were evaluated. The results of both assumption tests are consolidated in Table 12.

Using the Mahalanobis-distance and chi-square procedure specified in the study, the experimental group yielded a Pearson correlation coefficient of .685 ($p < .001$), whereas the control group yielded a coefficient of .666 ($p < .001$). According to the prespecified criterion used in this study, these results were interpreted as satisfying the multivariate-normality requirement.

Homogeneity of covariance matrices was evaluated using Box's M test. The analysis yielded Box's M = 1.704, F = 0.548, and p = .650. Because $p > .05$, the test provided no evidence that the covariance matrices differed between the experimental and control groups.

Table 12. Combined results of multivariate assumption testing

Assumption	Statistic	Experimental group	Control group	Decision
Multivariate normality	Mahalanobis-distance/chi-square Pearson correlation	r = .685, p < .001, n = 32	r = .666, p < .001, n = 30	Met according to the study's prespecified criterion
Homogeneity of covariance matrices	Box's M = 1.704; F = 0.548; df1 = 3; df2 = 753065.910; p = .650	-	-	No evidence of covariance-matrix heterogeneity

As summarized in Table 12, the assumptions used in the study were considered sufficiently satisfied to proceed with the multivariate comparison.

Multivariate and Follow-Up Between-Subjects Results

The one-way MANOVA showed a statistically significant multivariate difference between the experimental and control groups across the combined outcomes of scientific literacy and self-directed learning. Table 13 combines the original MANOVA results and the subsequent between-subjects tests.

Pillai's Trace was .958, $F(2, 59) = 671.689$, $p < .001$, with partial $\eta p^2 = .958$. The other multivariate statistics-Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root-produced the same inferential conclusion, as shown in Table 13. These results indicate a statistically significant overall group difference across the two dependent variables considered simultaneously.

The follow-up between-subjects tests showed a statistically significant group difference in scientific literacy, $F(1, 60) = 823.926$, $p < .001$, partial $\eta p^2 = .932$. A statistically significant group difference was also observed for self-directed learning, $F(1, 60) = 483.452$, $p < .001$, partial $\eta p^2 = .890$. Based on the effect-size interpretation specified in the revised Method section, both partial eta-squared values represent large effects.

Table 13. Combined MANOVA and follow-up between-subjects results

Analysis	Outcome/statistic	Value or Type III SS	F	df	p	Partial ηp^2	Interpretation
Multivariate	Pillai's Trace	.958	671.689	2, 59	< .001	.958	Significant multivariate group difference
Multivariate	Wilks' Lambda	.042	671.689	2, 59	< .001	.958	Significant multivariate group difference

Analysis	Outcome/statistic	Value or Type III SS	F	df	p	Partial ηp²	Interpretation
Multivariate	Hotelling's Trace	22.769	671.689	2, 59	< .001	.958	Significant multivariate group difference
Multivariate	Roy's Largest Root	22.769	671.689	2, 59	< .001	.958	Significant multivariate group difference
Between-subjects	Scientific literacy	Type III SS = 10,381.723	823.926	1, 60	< .001	.932	Significant group difference; large effect
Between-subjects	Self-directed learning	Type III SS = 6,176.786	483.452	1, 60	< .001	.890	Significant group difference; large effect

Taken together, the descriptive and inferential results show that the experimental group obtained higher posttest scores and larger descriptive gains in scientific literacy and self-directed learning than the control group. The MANOVA further identified a significant multivariate group difference, and the follow-up tests showed significant between-group differences for each outcome separately. Because the groups also differed descriptively at pretest, the findings are reported here as observed group differences and changes; their pedagogical interpretation and the implications of the initial group differences are addressed in the Discussion.

Discussion

Feasibility and Instructional Quality of the Discovery-Learning E-Module

Feasibility evaluation is an important stage in instructional-material development because it determines whether the content, instructional organization, presentation, and technical features of a product are sufficiently appropriate for subsequent implementation (Ningsih et al., 2026). In the present study, both the media and instructional-materials expert and the subject-matter expert rated the developed e-module as very feasible, as summarized in Table 9. The media and instructional-materials evaluation yielded an overall mean of 3.7, whereas the subject-matter evaluation yielded a mean of 3.5. These findings indicate that the product met the predetermined feasibility criteria across competency alignment, language, presentation, graphic design, usability, material accuracy, didactics, and construction.

These findings are consistent with previous studies showing that discovery-learning e-modules can satisfy feasibility requirements as instructional resources for developing students' scientific literacy (Khairunisa et al., 2025; Maghfiroh et al., 2023). They are also consistent with findings that e-modules incorporating local resources can provide appropriate instructional materials for scientific-literacy-oriented learning (Rediani et al., 2023; Setyorini et al., 2022). However, the contribution of the present product extends beyond combining an e-module with discovery learning. As shown in Figure 2 and Table 8, the local biodiversity of Kelimutu National Park was embedded within the instructional sequence as a source of stimulation, information gathering, data analysis, verification, and conclusion formation. Therefore, contextual content was integrated into the learning process rather than being presented merely as supplementary information.

The favorable feasibility evaluation can also be understood in relation to the technical and instructional characteristics of the product. Appropriate digital instructional materials require coherent organization, readable visual presentation, functional navigation, and content that supports interaction with the learning tasks (Bahi & Aloysius, 2025; Ningsih et al., 2026). These characteristics are represented in the developed e-module through its systematic organization, navigation features, contextual images and videos, worksheets, and sequential discovery-learning activities. The product was distributed as a digital flipbook, allowing students to access the same instructional content across multiple devices. This format also enabled the biodiversity of Kelimutu National Park to be represented through visual resources that students could repeatedly examine during learning.

Nevertheless, feasibility should be interpreted as evidence of the product's instructional and technical suitability rather than direct evidence of its effectiveness. Expert judgments establish whether the product is sufficiently appropriate for implementation, whereas evidence regarding its usability and learning outcomes must be considered separately through the practicality and effectiveness evaluations. This distinction is important because it prevents expert validation from being interpreted as evidence that the product itself has already improved student outcomes.

Practicality and Usability in Biology Learning

The practicality results complement the expert feasibility findings. As presented in Table 10, both biology teachers rated the e-module as very practical, with overall mean scores of 3.7 and 3.8, while the 35 students also provided an overall practicality score of 3.7. The maximum score assigned by both teachers to competency alignment suggests that the instructional activities were perceived as consistent with the intended learning competencies. From the students' perspective, the material received the highest score, followed by language, operation, and visual presentation. Together, these evaluations suggest that the e-module was understandable and manageable for its intended classroom users.

Several product features may account for these evaluations. Figure 2 illustrates the digital organization of the e-module, while Table 8 shows that learning activities were organized sequentially across the three instructional sessions. Clear instructions, accessible navigation, structured worksheets, and integration of images and videos reduce the need for students to locate different instructional components across separate resources. The digital flipbook format also permits access through different devices, supporting learning both inside and outside the classroom.

An additional practical advantage is the digital representation of Kelimutu National Park. Direct field observation in a national park may not always be feasible because of distance, time, logistics, or school resources. In this e-module, images and videos allow students to observe biodiversity-related examples from Kelimutu while remaining in the classroom. This digital representation does not replace authentic field experience, but it provides a practical means of bringing locally relevant biological phenomena into routine instruction. Thus, the practicality of the product derives not simply from its electronic format but from the combination of accessibility, structured instructional guidance, and contextually meaningful biological resources.

Scientific Literacy: From Contextual Phenomena to Evidence-Based Reasoning

The effectiveness findings indicate a consistent pattern favoring the experimental group for scientific literacy. As shown in Table 11, the experimental-group mean increased from 60.40 at pretest to 85.59 at posttest, representing a descriptive gain of 25.19 points, compared with an 8.87-point gain in the control group. After the multivariate assumptions summarized in Table 12 were considered satisfied, the inferential analysis presented in Table 13 identified a significant multivariate group difference. The follow-up test for scientific literacy also showed a significant between-group difference, $F(1, 60) = 823.926$, $p < .001$, with a large partial eta-squared value ($\eta p^2 = .932$). These results support the educational relevance of the developed e-module for scientific-literacy learning, although the magnitude of the effect should be interpreted within the design considerations discussed later.

The scientific-literacy outcome can be explained more meaningfully by examining the instructional alignment presented in Table 8 rather than by attributing it to the digital format alone. Scientific literacy requires students to engage with scientific phenomena, investigations, data, evidence, and scientific explanations. The discovery-learning sequence incorporated these processes directly into the learning activities. During stimulation, students encountered local, global, and personal contexts associated with biodiversity. During problem identification, they were required to explain phenomena and engage with epistemic knowledge. Data collection required students to search for and evaluate information, whereas data processing required them to organize and interpret evidence. Verification then required comparison and evaluation of findings, and the conclusion stage required students to formulate scientifically defensible explanations.

This alignment provides a plausible instructional mechanism for the observed outcomes because the learning activities repeatedly required students to perform processes closely related to the scientific-literacy competencies being assessed. Discovery learning can support such processes by positioning students as active investigators who construct understanding through guided exploration rather than simply receiving completed explanations (Tias et al., 2026). Previous empirical studies similarly report positive outcomes from discovery-oriented e-modules or learning environments for scientific literacy and related higher-order competencies (Khairunisa et al., 2025; Maghfiroh et al., 2023). Saputra & Octavia (2024), for example, found favorable outcomes from an augmented-reality-supported discovery e-module for higher-order thinking in biology, further illustrating the potential of digitally supported discovery activities.

The Kelimutu context appears to provide an additional pedagogical layer. Instead of asking students to reason exclusively from generalized textbook examples, the e-module presents biological phenomena associated with a recognizable environmental setting. Previous studies have suggested that connecting science learning with local species, environmental conditions, and community contexts can strengthen the relationship between scientific concepts and students' everyday experiences (Damopolii et al., 2024; Hidayat et al., 2024; Wardhani et al., 2023). Learning based on local potential can also provide authentic contexts for problem solving and scientific reasoning (Mashami et al., 2025; Nurhayati et al., 2025). A recent systematic review of place-based learning in K-12 science education similarly found that local environments are frequently used to promote authentic inquiry, understanding of human-environment relationships, scientific inquiry skills, and critical thinking, with biodiversity among the recurring instructional topics (Ge et al., 2026). This broader evidence supports the instructional rationale for using Kelimutu National Park as a context through which biodiversity concepts and scientific-literacy processes can be connected.

Accordingly, the contribution of the local context should not be interpreted simply as increasing students' familiarity with examples. Its more important function is to provide phenomena about which students can ask questions, seek evidence, organize information, compare findings, and construct explanations. In this sense, Kelimutu National Park functions as a contextual scientific resource within the discovery process.

Self-Directed Learning: Structured Responsibility Within Discovery Learning

A comparable pattern was observed for self-directed learning. Table 11 shows that the experimental-group mean increased from 63.46 to 86.90, a descriptive gain of 23.44 points, whereas the control-group mean increased by 10.27 points. The follow-up analysis in Table 13 identified a significant between-group difference in self-directed learning, $F(1, 60) = 483.452$, $p < .001$, with a large partial eta-squared value ($\eta p^2 = .890$). These findings are consistent with the expectation that instructional activities requiring students to assume progressively greater responsibility for learning can support self-directed-learning development.

Importantly, the e-module did not conceptualize self-directed learning as students learning entirely without teacher guidance. Instead, independence was structured through the discovery-learning sequence. As mapped in Table 8, students were expected to engage with learning materials independently during stimulation, demonstrate self-initiative when identifying problems, exercise self-discipline during information gathering, develop confidence while processing evidence, and take responsibility for the conclusions they produced. Thus, students were provided with a structured sequence within which responsibility for specific learning decisions and tasks was progressively transferred to them.

This interpretation is consistent with the characteristics of discovery learning described by Manurung & Pappachan (2025), who emphasize students' active involvement in discovering procedures, principles, and concepts. Hariyanto et al. (2023) similarly argue that discovery activities require learners to develop problem-solving steps, seek information, and formulate conclusions from collected evidence. These processes overlap substantially with the behavioral characteristics targeted by the self-directed-learning instrument used in the present study, particularly self-initiative, self-discipline, confidence, and personal responsibility.

Recent synthesis evidence further supports this interpretation. Kaya et al. (2026) concluded from a second-order meta-analysis that self-directed learning is most appropriately understood not as unrestricted independence but as the deliberate transfer of learning responsibility through structured pedagogical support. Their synthesis also reported positive effects of self-directed-learning-oriented interventions across academic outcomes, self-regulation strategies, and skill-based outcomes. This perspective helps explain why combining an e-module with an explicit discovery-learning sequence may be more important than simply providing students with digital materials for independent use.

The Contribution of Kelimutu National Park as a Context for Independent and Meaningful Learning

The local context may also contribute to self-directed learning by making the information-seeking process more concrete and purposeful. Students were asked to investigate biodiversity associated with Kelimutu National Park using the images and videos embedded in the e-module and additional sources identified during data collection. Their findings were subsequently organized in worksheets, compared with peer findings, and used to formulate conclusions. Consequently, students had a recognizable environmental context around which to organize independent information seeking and analysis.

Previous research indicates that connecting learning with local resources and culture can encourage students to engage more actively with problems and can support critical thinking, creativity, and confidence in problem solving (Arjaya et al., 2024). Puspita et al. (2024) similarly emphasize that locally grounded learning can make abstract learning content more accessible by linking it to environments and experiences that students can recognize. Findings concerning learning independence are also consistent with Widyaningrum & Prihastari (2023), who reported positive outcomes from the integration of local resources into learning, and with Fajeriadi et al. (2025), who found that biology learning resources based on local potential can support student competencies, including greater independence in learning.

The present study therefore suggests that the educational contribution of the Kelimutu context lies in the interaction between place and pedagogy. Recent reviews of place-based education characterize local environments as resources for contextual, experiential, and inquiry-oriented learning rather than merely as examples added to conventional instruction (Ge et al., 2026). In the present e-module, the local context supplied the phenomena and information resources, while discovery learning supplied the sequence through which students interacted with those resources. This interaction may explain why the e-module could simultaneously address scientific reasoning and learner responsibility.

This interpretation also clarifies an important conceptual distinction. The primary contextual element examined in this study is the local biodiversity and environmental potential of Kelimutu National Park. Although cultural values may form part of the broader social setting surrounding the national park, the instructional intervention reported here is principally grounded in local biological resources. Therefore, the findings are more appropriately interpreted as evidence concerning locally contextualized biology learning rather than generalized evidence regarding 'local wisdom' in all of its cultural dimensions.

Integrated Contribution and Boundaries of the Effectiveness Evidence

Taken together, the findings suggest that the contribution of the developed product arises from the alignment of three components: digital accessibility, the discovery-learning process, and the local biodiversity context. Figure 2 demonstrates how these components are represented in the e-module interface and learning materials, whereas Table 8 shows how the discovery stages were deliberately mapped onto scientific-literacy and self-directed-learning indicators. Tables 9 and 10 establish that experts and users considered the resulting product feasible and practical, while Tables 11-13 provide descriptive and inferential evidence concerning student outcomes. The value of the study therefore lies not merely in producing another electronic module but in designing a digital instructional environment in which the local context provides authentic content and discovery learning structures students' engagement with that content.

At the same time, the effectiveness findings require cautious interpretation. As shown in Table 11, the experimental group already had higher pretest means than the control group for both scientific literacy (60.40 vs. 50.83) and self-directed learning (63.46 vs. 56.66). The significant post-intervention group differences reported in Table 13 therefore cannot be interpreted as if the two groups had identical starting conditions. In pretest-posttest studies involving pre-existing or nonequivalent groups, baseline differences can complicate the interpretation of posttest comparisons and change scores (van Breukelen, 2013). For this reason, the present findings are most appropriately interpreted as showing that the experimental group achieved higher posttest scores and larger descriptive gains during implementation of the developed e-module, rather than as establishing an unqualified causal estimate of the treatment effect.

This qualification does not negate the observed pattern. The experimental group showed consistently greater descriptive improvement in both outcomes, the multivariate comparison was statistically significant, and the follow-up analyses produced large effect sizes. Rather, it defines the evidential boundary of the quasi-experimental design. Future studies could strengthen causal interpretation by involving more schools and classes, improving baseline comparability, extending the duration of implementation, and applying analytical approaches that explicitly account for initial group differences.

Overall, the results support the educational potential of integrating discovery learning with the local biodiversity of Kelimutu National Park in a flexible digital e-module. The instructional sequence provides students with structured opportunities to observe contextual phenomena, identify problems, gather and interpret evidence, verify findings, and construct conclusions while progressively assuming responsibility for their learning. This combination provides a plausible explanation for the concurrent development of scientific literacy and self-directed learning observed in the experimental group and highlights the potential of locally contextualized digital resources for meaningful biodiversity education.

CONCLUSIONS

This study developed a discovery-learning e-module integrating the local biodiversity potential of Kelimutu National Park for Phase E biology learning. The product met the predetermined feasibility and practicality criteria based on evaluations by media and instructional-materials experts, a subject-matter expert, biology teachers, and students. These evaluations indicate that the e-module is instructionally appropriate, understandable, accessible, and practical for classroom use. Its digital flipbook format, clear instructional guidance, navigational features, and integration of contextual images, videos, worksheets, and learning activities support its use both inside and outside the classroom.

The effectiveness evaluation also showed a consistent pattern in favor of the experimental group. Students who learned using the developed e-module achieved higher posttest scores and larger descriptive gains in both scientific literacy and self-directed learning than students in the control group. These findings were supported by significant multivariate and follow-up between-group differences. However, because the experimental and control groups differed in their initial pretest scores, these results should be interpreted as evidence supporting the educational potential of the e-module rather than as an unqualified causal estimate of its effect.

The instructional contribution of the e-module lies in the alignment between discovery-learning activities, scientific-literacy competencies, self-directed-learning indicators, and the local biodiversity context of Kelimutu National Park. Through stimulation, problem identification, data collection, data processing, verification, and conclusion formation, students were provided with structured opportunities to observe contextual biological phenomena, seek and evaluate information, interpret evidence, formulate explanations, and take increasing responsibility for their learning. Thus, the Kelimutu context functioned not merely as supplementary information but as a contextual resource through which students engaged in scientific reasoning and independent learning activities.

These findings have practical implications for biology education, particularly in East Nusa Tenggara. Kelimutu National Park provides a rich source of biodiversity and environmental phenomena that can be transformed into contextual instructional resources without requiring students to visit the location directly. Representing these resources through images, videos, and structured discovery activities enables students to engage with locally relevant biodiversity while learning scientific concepts. The developed e-module therefore illustrates how local environmental resources can be integrated with digital technology and an explicit pedagogical model to support meaningful biology learning.

Beyond the immediate study setting, the e-module has the potential to be adapted and evaluated in schools outside East Nusa Tenggara because the biodiversity context is represented digitally and can be accessed without direct geographical proximity to Kelimutu National Park. Nevertheless, implementation in different regions should not be assumed to produce identical outcomes. Adaptation to students' characteristics, curricular needs, technological access, and local learning contexts should be considered before broader use. Accordingly, the main contribution of this study is not simply the production of a digital module, but the demonstration of a design approach that integrates discovery learning, local biodiversity, and flexible digital access to simultaneously support scientific literacy and self-directed learning.

RECOMMENDATIONS

Several limitations should be considered when interpreting the findings and designing future studies. First, the effectiveness evaluation involved a limited number of students from a single school setting. Consequently, the findings cannot yet be generalized to schools with different student populations, institutional characteristics, technological resources, or learning environments. Future studies should evaluate the e-module across multiple schools and more diverse student populations to determine whether the observed patterns are consistent across educational contexts.

Second, the experimental and control groups showed different pretest means for both scientific literacy and self-directed learning. Because the effectiveness study used a nonequivalent control-group design, these initial differences limit the strength of causal conclusions based solely on posttest comparisons. Future research should employ designs that improve baseline comparability between groups or use appropriate analytical procedures that explicitly account for pre-intervention differences. Replication using larger samples, additional classes, or randomized assignment where feasible would further strengthen the evidence regarding the effectiveness of the e-module.

Third, self-directed learning was measured using a self-assessment instrument. Although the instrument met the validity and reliability criteria used in this study, self-report measures may still be influenced by students' subjective perceptions, response tendencies, and differences between perceived and actual learning behavior. Future research should therefore combine self-assessment with complementary sources of evidence, such as classroom observations, teacher assessments, interviews, learning journals, worksheet completion patterns, or digital learning-activity records. Such triangulation would provide a more comprehensive representation of how students actually exercise initiative, discipline, confidence, and responsibility during learning.

Fourth, the intervention was implemented over three learning sessions. The present study therefore provides evidence regarding relatively short-term learning outcomes but does not establish whether the observed differences in scientific literacy and self-directed learning are sustained over longer periods. Future studies should extend the duration of implementation and, where possible, include delayed assessments to examine retention and the longer-term development of both competencies.

Future development may also examine how the same instructional framework can be adapted to other biodiversity topics, ecosystems, or locally relevant environmental contexts. Rather than simply transferring the Kelimutu content unchanged, researchers and teachers could retain the underlying design principle-integrating authentic local phenomena with discovery-learning activities and digital resources-while adapting the contextual content to the ecological characteristics of different regions. Such studies would help determine whether the design approach is transferable beyond the specific context of Kelimutu National Park.

Acknowledgment
The authors thank Public High School 1 Ende and St. Thomas Morus High School for facilitating the research and Yogyakarta State University for providing administrative support. The authors also acknowledge the use of ChatGPT (OpenAI) as an assistive tool for language editing and structural organization of the manuscript. The authors critically reviewed and approved all revisions and remain fully responsible for the accuracy, interpretation, and integrity of the manuscript. DeepL Translate Pro and Grammarly Pro were also used to support translation and English-language editing.

Funding Information
This research received no external funding.

Conflict of Interest Statement
The authors declare no conflict of interest.

Data Availability
The research data are available from the corresponding author upon reasonable request. Requests may be directed to mariaoctaviani.2022@student.uny.ac.id.

Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
MO Inggrita Mesa	✓	✓	✓		✓	✓	✓		✓		✓		✓	
Suyitno Aloysius				✓				✓		✓		✓	✓	

C : Conceptualization I : Investigation Vi : Visualization

M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

REFERENCES

Alfi, B. R., Paidi, P., & Pratama, A. T. (2024). Validating instrument to assess science literacy and independent learning skills in high school. *JPBI (Jurnal Pendidikan Biologi Indonesia), 10*(3), 979-988. https://doi.org/10.22219/jpbi.v10i3.34770

Anayanti, D. K., & Zainuddin, A. (2025). The influence of parenting style and teacher's teaching style on student learning independence. *Scaffolding: Jurnal Pendidikan Islam dan Multikulturalisme, 7*(1), 164-183. https://doi.org/10.37680/scaffolding.v7i1.6901

Arjaya, I. B. A., Suastra, I. W., Redhana, I. W., & Sudiatmika, A. A. I. A. R. (2024). Global trends in local wisdom integration in education: A comprehensive bibliometric mapping analysis from 2020 to 2024. *International Journal of Learning, Teaching and Educational Research, 23*(7), 120-140. https://doi.org/10.26803/ijlter.23.7.7

Ayu, G. N., Putri, C. A., Riyanto, A. R., & Koto, I. (2025). The scientific literacy competence of students in Indonesia and Mexico based on PISA 2022: An international comparative study. *The Future of Education Journal, 4*(5), 1033-1038. https://doi.org/10.61445/tofedu.v4i5.525

Bahi, N., & Aloysius, S. (2025). How can the development of e-modules PBL improve students critical thinking skills and independent in biology learning? *JPBI (Jurnal Pendidikan Biologi Indonesia), 11*(3), 983-998. https://doi.org/10.22219/jpbi.v11i3.42399

Berliana, G. Y., Sugiyanto, S., & Fardhani, I. (2023). Student's learning outcomes and scientific literacy improvement through the implementation of reading to learn and discovery learning models. *Jurnal Penelitian Pendidikan IPA, 9*(5), 2563-2572. https://doi.org/10.29303/jppipa.v9i5.2573

Branch, R. M. (2010). *Instructional design: The ADDIE approach*. Springer. https://doi.org/10.1007/978-0-387-09506-6

Bórquez-Sánchez, E. (2025). Scientific literacy in biology and attitudes towards science in the Chilean education system. *Research in Science & Technological Education, 43*(2), 589-613. https://doi.org/10.1080/02635143.2024.2320104

Budiastuti, R., & Mercuriani, I. S. (2025). Development of innovative technology electronic modules based on orchid potential in Nglanggeran forest through project-based learning on biotechnology material to enhance science literacy and learning interest of high school students. *Jurnal Penelitian Pendidikan IPA, 11*(1), 1057-1065. https://doi.org/10.29303/jppipa.v11i1.9410

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. SAGE Publications.

Damopolii, I., Nunaki, J. H., Jeni, J., Rampheri, M. B., & Ambusaidi, A. K. (2024). An integration of local wisdom into a problem-based student book to empower students' conservation attitudes. *Participatory Educational Research, 11*(1), 158-177. https://doi.org/10.17275/per.24.10.11.1

Fajeriadi, H., Azzam, M. N., & Azzahra, F. G. (2025). The effect of local potential-based biology learning resources on students' competencies: An in-depth analysis. *Biosfer, 18*(2), 315-326. https://doi.org/10.21009/biosferjpb.54745

Fitrianawati, M., & Noerazizah, A. S. (2025). The impact of renewable energy learning media based on local wisdom on critical thinking skills. *International Journal of Learning Reformation in Elementary Education, 4*(1), 18-26. https://doi.org/10.56741/ijlree.v4i01.763

Ge, J., Cheng, J., Liang, X., & Zhang, J. (2026). Place-based learning in K-12 science education: A systematic review. *Educational Research Review, 52*, 100826. https://doi.org/10.1016/j.edurev.2026.100826

Graham, A., Powell, M. A., Anderson, D., Fitzgerald, R., & Taylor, N. (2013). *Ethical research involving children*. UNICEF Office of Research-Innocenti.

Hariyanto, H., Hikamah, S. R., Maghfiroh, N. H., & Priawasana, E. (2023). The potential of the discovery learning model integrated the reading, questioning, and answering model on cross-cultural high school students' problem-solving skills. *Journal of Education and Learning, 17*(1), 58-66. https://doi.org/10.11591/edulearn.v17i1.20599

Hidayat, A. E., Wisanti, W., & Isnawati, I. (2024). Biological literacy skills of senior high school student using local potential-based biodiversity question sets. *JPBI (Jurnal Pendidikan Biologi Indonesia), 10*(3), 724-734. https://doi.org/10.22219/jpbi.v10i3.35571

Homsombat, P. (2025). Integrating local wisdom and modern education: A holistic approach to curriculum development. *Journal of Exploration in Interdisciplinary Methodologies, 2*(3), 66-83. https://so19.tci-thaijo.org/index.php/JEIM

Hopipah, R., Sofyan, H., & Haryanto, E. (2025). The influence of the discovery learning model on enhancing motivation and learning outcomes in natural and social sciences (IPAS) among students. *Jurnal Penelitian Pendidikan IPA, 11*(3), 230-236. https://doi.org/10.29303/jppipa.v11i3.9750

Juandi, D., Kusumah, Y. S., Tamur, M., Perbowo, K. S., Siagian, M. D., Sulastri, R., & Negara, H. R. P. (2021). The effectiveness of dynamic geometry software applications in learning mathematics: A meta-analysis study. *International Journal of Interactive Mobile Technologies, 15*(2), 18-37. https://doi.org/10.3991/ijim.v15i02.18853

Judijanto, L., Yudha Santoso, R., Megah Retta, L., & Sarkawi, S. (2024). Strategy of integration of local wisdom in the curriculum of higher education. *International Journal of Teaching and Learning, 2*(6), 1537-1546. https://injotel.org/index.php/12/article/view/181

Kaya, M., Güvercin Seçkin, G., & Arslan, Z. (2026). The effects of self-directed learning-oriented interventions on student learning outcomes: A second-order meta-analysis. *International Journal of Educational Research*, 103071. https://doi.org/10.1016/j.ijer.2026.103071

Khairani, R. N., & Prodjosantoso, A. K. (2023). Application of discovery learning model based on blended learning to activities and learning outcomes. *Jurnal Penelitian Pendidikan IPA, 9*(10), 8974-8981. https://doi.org/10.29303/jppipa.v9i10.4402

Khairunisa, K., Violita, V., Arsih, F., Chatri, M., Anhar, A., & Fransisca, R. (2025). Development of biology module based on discovery learning and ethnoscience to improve students' science literacy. *JPBI (Jurnal Pendidikan Biologi Indonesia), 11*(3), 895-907. https://doi.org/10.22219/jpbi.v11i3.41861

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Maghfiroh, S., Wilujeng, I., Jumadi, J., & Masyitha, D. (2023). Development of physics e-module based on discovery learning to improve students' scientific literacy. *Jurnal Penelitian Pendidikan IPA, 9*(2), 452-458. https://doi.org/10.29303/jppipa.v9i2.1733

Mahdi, M., Raharjo, T. J., & Widiasih, W. (2023). Analysis of problem solving ability in natural sciences and life skills through guided discovery learning in the view of student learning independence in the subject matter of changes in energy forms. *Jurnal Penelitian Pendidikan IPA, 9*(12), 11093-11100. https://doi.org/10.29303/jppipa.v9i12.5289

Manurung, A. S., & Pappachan, P. (2025). The role of discovery learning in efforts to develop students' critical thinking abilities. *Journal of Education and Learning, 19*(1), 46-53. https://doi.org/10.11591/edulearn.v19i1.21788

Mashami, R. A., Ahmadi, A., & Pahriah, P. (2025). Green chemistry and cultural wisdom: A pathway to improving scientific literacy among high school students. *Social Sciences & Humanities Open, 11*, 101653. https://doi.org/10.1016/j.ssaho.2025.101653

Niate, M., & Paidi, P. (2025). Development of SETS e-module on endocrine system material to improve scientific literacy and learning independence of high school students. *BIO-INOVED: Jurnal Biologi-Inovasi Pendidikan, 7*(2), 308. https://doi.org/10.20527/bino.v7i2.21357

Ningsih, H., Rokhman, F., Pramono, S. E., & Raharjo, T. J. (2026). Kelayakan bahan ajar interaktif sistem pernapasan manusia pada keterampilan berpikir kritis siswa kelas V SD. *Pendas: Jurnal Ilmiah Pendidikan Dasar, 11*(1). https://doi.org/10.23969/jp.v11i01.40045

Novalia, R., Marini, A., Bintoro, T., & Muawanah, U. (2025). Project-based learning: For higher education students' learning independence. *Social Sciences & Humanities Open, 11*, 101530. https://doi.org/10.1016/j.ssaho.2025.101530

Nurhayati, N., Jaenudin, D., & Sukmanasa, E. (2025). Development of e-modules based on local wisdom on ecosystem material to increase scientific literacy. *AL-ISHLAH: Jurnal Pendidikan, 17*(1). https://doi.org/10.35445/alishlah.v17i1.6224

Nurohman, S., & Fikri, I. (2025). Science e-book integrated with local potential of petis making based on problem based learning-ESD to improve science literacy skills of junior high school students. *Jurnal Penelitian Pendidikan IPA, 11*(1), 1039-1048. https://doi.org/10.29303/jppipa.v11i2.7956

OECD. (2023). *PISA 2022 results (Volume I): The state of learning and equity in education*. OECD Publishing. https://doi.org/10.1787/53f23881-en

Pamungkas, J., Harun, H., & Manaf, A. (2023). A systematic review and meta-analysis group contrasts: Learning model based on local cultural wisdom and student learning outcomes. *International Journal of Instruction, 16*(2), 53-70. https://doi.org/10.29333/iji.2023.1624a

Pantiwati, Y., Aminudin, A., Waluyo, L., Permana, F. H., Sari, T. N. I., & Nurrohman, E. (2025). E-module based on LI-PRO-GP learning model to improve students' conceptual understanding and problem-solving abilities in science learning. *International Journal of Information and Education Technology, 15*(3), 549-564. https://doi.org/10.18178/ijiet.2025.15.3.2265

Pratama, A., Sari, T. N. I., Istiqomah, N., Widiyanti, E. R., & Kusniati, Y. (2024). Improving critical thinking and metacognitive skills through the discovery learning model assisted by practicum for high school students. *Biosfer, 17*(1), 102-112. https://doi.org/10.21009/biosferjpb.34481

Prihatiningtyas, S., Shofiyah, N., Yunus, S. R., Ma'arif, I. B., & Putra, I. A. (2025). Enhancing science literacy through flipbook-based STEM Qur'an e-modules: A case study in Islamic boarding schools. *Humanities and Social Sciences Communications, 12*(1). https://doi.org/10.1057/s41599-025-05054-w

Puspita, H., Firdaus, F. M., & Kawuryan, S. P. (2024). Self-directed learning model based on local wisdom values on student learning outcomes. *Journal of Innovation in Educational and Cultural Research, 5*(1), 22-28. https://doi.org/10.46843/jiecr.v5i1.839

Rediani, N. N., Kaize, B. R., Hanifah, S., Nainggolan, H. T., Dharma Sanjaya, P. M., & Hallatu, T. G. R. (2023). Developing environmental care attitudes and scientific literacy through Sasi local wisdom-based e-modules. *Jurnal Pedagogi dan Pembelajaran, 6*(2), 238-246. https://doi.org/10.23887/jp2.v6i2.64518

Richardson, J. T. E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review, 6*(2), 135-147. https://doi.org/10.1016/j.edurev.2010.12.001

Salim Putra, M. D. F., Subali, B., & Marwoto, P. (2025). Development of STEM based physics e-module with virtual lab to improve learning outcomes. *Physics Communication, 9*(1), 63-70. https://doi.org/10.15294/pc.v9i1.8343

Saputra, R. S., & Octavia, B. (2024). E-module assisted by augmented reality with a discovery learning model on virus material to increase scientific literacy and learning independence for class X high school students. *Jurnal Penelitian Pendidikan IPA, 10*(11), 8507-8518. https://doi.org/10.29303/jppipa.v10i11.8795

Sari, T. N. I., Pantiwati, Y., & Fauzi, A. (2024). Development of four-tier multiple-choice diagnostic instrument to identify middle school students' misconceptions about biology material. *Biosfer: Jurnal Pendidikan Biologi, 17*(1), 257-273. https://doi.org/10.21009/biosferjpb.35289

Sari, T. N. I., Rakhmawati, A., & Rahmawati, H. R. (2025). Effectiveness of PjBL worksheet based on local potential to improve critical and creative thinking skills of Phase E high school students. *Journal of Innovation in Educational and Cultural Research, 6*(2), 242-252. https://doi.org/10.46843/jiecr.v6i1.1836

Sayangan, Y. V. (2024). A qualitative study on the impact of local wisdom-based discovery learning in teaching concept geometry. *Al-Jabar: Jurnal Pendidikan Matematika, 15*(1). http://ejournal.radenintan.ac.id/index.php/al-jabar/index

Sele, Y., Sila, V. U. R., Oetpah, F., & Kabnani, Y. (2023). Students' learning independence from different specialization classes: A comparative study. *Jurnal Pembelajaran dan Biologi Nukleus, 9*(1), 57-65. https://doi.org/10.36987/jpbn.v9i1.3925

Setyaningsih, A., Kholik, N., Azis, A. A., Yusnanto, T., & Sadikin, A. (2023). The effect of learning environment and students independent learning on students learning outcomes. *Jurnal Manajemen Pendidikan, 5*(1), 142-147. https://doi.org/10.55352/mudir

Setyorini, L., Haryani, S., & Susilaningsih, E. (2022). Development of e-module based on local wisdom to improve science literacy and reading literacy. *Jurnal Pendidikan Kimia, 14*(1), 28-38. https://doi.org/10.24114/jpkim.v14i1.32948

Shaydulloyevich, B. Q. (2025). Improving lesson effectiveness through engineering students' independent learning. *Current Research Journal of Pedagogics, 6*(12), 23-26. https://doi.org/10.37547/pedagogics-crjp-06-12-06

Sidauruk, S., Ni'mah, F., Meiliawati, R., Analita, R. N., Rahmadani, A., Budi, F. S., & Adhani, A. (2025). Scientific literacy on peatland across various study programs, genders, and current domicile of university students in Borneo. *Journal of Education and Learning, 19*(1), 449-459. https://doi.org/10.11591/edulearn.v19i1.21794

Sidauruk, T., Delita, F., Berutu, N., Elfayetti, E., & Rohani, R. (2025). E-modules to improve learning independence, motivation and learning outcomes. *Jurnal Penelitian dan Pengembangan Pendidikan, 9*(1), 171-180. https://doi.org/10.23887/jppp.v9i1.74404

Sjöström, J. (2025). Vision III of scientific literacy and science education: An alternative vision for science education emphasising the ethico-socio-political and relational-existential. *Studies in Science Education, 61*(2), 239-274. https://doi.org/10.1080/03057267.2024.2405229

Susilawati, S., Mulyani, G., Halim, A., Saputri, M., Farhan, A., & Widia, S. (2025). Enhancing scientific literacy through an interactive e-module enriched with Acehnese local wisdom. *Journal of Physics: Conference Series, 3148*(1), 012008. https://doi.org/10.1088/1742-6596/3148/1/012008

Syahira, H. Q., Pursitasari, I. D., Retnowati, R., & Syarpin, S. (2025). E-module of the human digestive system with self-directed learning readiness framework to improve students' science literacy. *Jurnal IPA dan Pembelajaran IPA, 9*(4), 1070-1085. https://doi.org/10.24815/jipi.v9i4.48969

Tias, D. E. Y., Atmaja, I. W. W., Emyus, A. Z., & Priawasana, E. (2026). Discovery learning combined with the RQA strategy to strengthen science literacy and basic thinking skills in elementary school students. *Jurnal Penelitian Pendidikan IPA, 12*(1), 210-224. https://doi.org/10.29303/jppipa.v12i1.13876

Utama, N., & Zulyusri, Z. (2022). Meta-analisis praktikalitas penggunaan e-modul oleh guru dan peserta didik dalam pembelajaran. *Jurnal Biologi dan Pembelajarannya, 9*, 27-33. https://ojs.unpkediri.ac.id/index.php/biologi

Utaminingsih, S., Fathurrahman, I., & Zuliyanti, N. (2022). E-module with discovery learning model based on educational games. *KnE Social Sciences*, 532-544. https://doi.org/10.18502/kss.v7i14.12006

van Breukelen, G. J. P. (2013). ANCOVA versus CHANGE from baseline in nonrandomized studies: The difference. *Multivariate Behavioral Research, 48*(6), 895-922. https://doi.org/10.1080/00273171.2013.831743

Wardhani, D. F., Arisanty, D., Nugroho, A., & Utami, U. B. L. (2023). The local wisdom of the Paramasan Dayak tribe in environmental management. *Environment and Ecology Research, 11*(5), 859-872. https://doi.org/10.13189/eer.2023.110514

Wege, K., Harso, A., & Wolo, D. (2022). Analysis of student learning independence during the pandemic. *Journal of Research in Instructional, 2*(1), 87-96. https://doi.org/10.30862/jri.v2i1.34

Widyaningrum, R., & Prihastari, E. B. (2023). Implementing local wisdom-integrated project-based learning model to instill students' learning independence. *SHS Web of Conferences, 173*, 01011. https://doi.org/10.1051/shsconf/202317301011

Wisdayana, N., Achyani, A., & Aththibby, A. R. (2025). Teaching materials based on socio scientific issues: An effective strategy to improve science literacy and critical thinking skills. *Jurnal Penelitian Pendidikan IPA, 11*(4), 346-354. https://doi.org/10.29303/jppipa.v11i4.10786

Yerimadesi, Y., Warlinda, Y. A., Rosanna, D. L., Sakinah, M., Putri, E. J., Guspatni, G., & Andromeda, A. (2023). Guided discovery learning-based chemistry e-module and its effect on students' higher-order thinking skills. *Jurnal Pendidikan IPA Indonesia, 12*(1), 168-177. https://doi.org/10.15294/jpii.v12i1.42130

Zahara, L., Santosa, M. H., & Widiana, I. W. (2025). A study of physics scientific literacy and students' learning independence in three subdistricts of East Lombok. *Jurnal Penelitian Pendidikan IPA, 11*(12), 308-315. https://doi.org/10.29303/jppipa.v11i12.13243