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Enhancing Scientific Literacy and Numeracy Using Ethnobiology E-Modules Integrated with AK-Based Multimodal Learning Activities

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Abstract: Indonesia's scientific literacy and numeracy skills remain relatively low compared to those of other countries. This deficiency is often linked to factors such as inappropriate textbooks, non-contextual learning, and low reading proficiency. This study aimed to determine the effect of an interactive, ethnobiology-based e-module, integrated with Visual, Auditory, and Kinesthetic (VAK)-based multimodal learning activities, on students' numeracy and scientific literacy skills in biodiversity material, considering different learning styles. This study employed a quantitative approach using a posttest-only quasi-experimental design with a 2 × 3 factorial structure. The population comprised all tenth-grade students at SMA Negeri 1 Indramayu. Two classes, X-4 (experimental) and X-3 (control), were selected through cluster random sampling at the class level, with a total of 87 students (43 in the experimental class and 44 in the control class). The experimental class learned through an interactive ethnobiology-based e-module accompanied by multimodal visual, auditory, and kinesthetic activities. Meanwhile, the control class learned through the school's conventional instruction using PowerPoint, textbook-based explanation, teacher-led discussion, and instructional videos. Data analysis was conducted using a two-way ANOVA test on the composite posttest score. The results indicated a highly significant difference in students' posttest achievement between the experimental group and the control group (sig. 0.000<0.05). Conversely, learning style alone did not show a significant difference (sig. 0.303>0.05). Furthermore, the analysis revealed no significant interaction between the use of the e-module and students' learning styles (sig. 0.510>0.05). These findings indicate that, within this research context, the ethnobiology-based interactive e-module effectively supported higher students' numeracy and scientific literacy skills, irrespective of their individual learning styles. The study contributes empirical evidence that contextualized digital teaching materials support science learning while also showing that multimodal instruction may be more influential than learning-style categorization itself.
Keywords: Biodiversity, ethnobiology, interactive e-module, learning styles, numeracy, scientific literacy.

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INTRODUCTION

The progress of a nation is significantly dependent on the level of scientific literacy and numeracy. Numeracy is defined as the ability to utilize number concepts and mathematical skills in daily activities, including understanding and analyzing quantitative information from the surroundings (Chang, 2023; Díez-Palomar et al., 2023; Reyna et al., 2009). Strong numeracy skills are vital in various aspects of life, such as strengthening financial comprehension, opening career opportunities, and building a solid mathematical foundation for lifelong learning (Babashahi et al., 2024; Gal et al., 2020; Shan et al., 2023). Furthermore, numeracy enables individuals to understand data related to health, politics, and economics, often presented in numbers or graphs (Ayuntya & Nuryady, 2025; Azaria & Nuryady, 2025; Fauzi & Fatmawati, 2025; Husamah et al., 2025; Junes et al., 2025; Rahma et al., 2025; Satria et al., 2025; Werdianto et al., 2025). Good numeracy skills are foundational to scientific literacy, as the ability to understand numerical data, graphs, and statistics forms the basis for in-depth scientific analysis (Gal et al., 2020; Pratiwi & Yamtinah, 2025; Schapira et al., 2012).

Scientific literacy, meanwhile, is defined as an individual's capacity to understand, communicate, and apply scientific knowledge to solve various problems, while also raising environmental awareness. A person with scientific literacy can use scientific concepts and process skills to evaluate and make informed decisions (Afriana et al., 2016; Andriani et al., 2025; Chalisah et al., 2022; Kelp et al., 2023; Pratiwi & Yamtinah, 2025; Virtič, 2022). Scientific literacy focuses on developing students' knowledge to simplify and apply scientific concepts, think critically, and make balanced decisions when facing different issues. This ability is crucial for students to analyze problems and link them with scientific facts, particularly when making decisions related to natural phenomena and their impact on human activities (Alfi et al., 2024; Norambuena-Meléndez et al., 2023).

Despite its importance, the scientific literacy and numeracy skills of Indonesian students remain relatively low and lag behind those of other countries. Data from the Programme for International Student Assessment (PISA) show that Indonesian students obtained an average score of 383 in reading literacy and 366 in mathematics, both of which remain far below the OECD benchmark of approximately 500 points (OECD, 2023). Several factors contribute to this low performance, including the use of inappropriate textbooks, non-contextual learning, low reading skills, deficiencies in human resources, and school management issues (Astawan et al., 2025; Ginting et al., 2026; Sarimanah et al., 2022). Preliminary findings gathered through interviews with a biology teacher at SMA Negeri 1 Indramayu, West Java, Indonesia, indicated that while students were generally able to explain phenomena with teacher guidance, only a small fraction could answer questions by presenting scientific evidence or analyzing data in tables, images, or graphs. Most students struggled to evaluate and design scientific investigations, even with direction. This issue is compounded by the continued reliance on conventional teaching methods, such as lectures and reading textbooks, and the dominance of standard, non-interactive package books. These conventional materials often fail to cater to students' diverse learning needs, leading to disengagement, difficulty in comprehension, and suboptimal learning outcomes. Consequently, the numeracy and scientific literacy skills of students at SMA Negeri 1 Indramayu are currently not optimized.

To address these critical learning gaps, there is an urgent need for innovative instructional support, such as the use of effective teaching materials or modules. Students also differ in how they respond to instructional representation and classroom activities. In school practice, these differences are often discussed using the categories of visual, auditory, and kinesthetic (VAK) learning styles. However, it needs to note that VAK is more appropriately positioned as a description of learner preference than as a formal learning model with fixed syntactic stages (Novinovrita & Setiawan, 2025; Yotta, 2023). In addition, the concept of learning styles remains debated in the literature, and empirical findings do not always support the assumption that matching instruction to learning style categories will improve achievement. Therefore, in the present study, learning style was retained as an analytical factor rather than treated as the main theoretical basis of instruction. The instructional emphasis was placed on multimodal learning activities that provide visual, auditory, and kinesthetic access to the same content (Cassidy, 2004; Clinton-Lisell & Litzinger, 2024; J. Hattie & O'Leary, 2025; Hu et al., 2021; Lyle et al., 2023). Recognizing that students possess inherent differences in learning pace and ability, teachers must understand these variations, particularly the distinct learning styles (Langelaan et al., 2024; Romanelli et al., 2009). Previous studies have widely discussed digital modules, science literacy, numeracy, and contextual learning separately (Alim et al., 2025; Hamidah et al., 2025; Hidayanthi et al., 2024; Hillmayr et al., 2020; Idrissi, 2025; Munawaroh et al., 2023; Nst & Ariyanti, 2025; Reddy et al., 2021; Sumardi, 2025; Yerimadesi et al., 2026). However, a limited number of studies have examined: (1) ethnobiology-based e-modules in biodiversity learning, (2) two outcomes simultaneously, namely numeracy and scientific literacy, and (3) the role of learning-style categories within multimodal digital instruction. Thus, the novelty of this study lies in testing a contextualized ethnobiology e-module alongside VAK-based multimodal activities in a 2 × 3 factorial framework to investigate whether instructional treatment, learning-style category, and their interaction are associated with students' posttest achievement.

Based on this rationale, the study aimed to determine the differences in students' numeracy and scientific literacy achievement after learning with an interactive ethnobiology-based e-module accompanied by VAK-based multimodal activities, compared with conventional instruction, across

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three learning-style categories. The study tested three hypotheses: H1, there is a significant difference in posttest achievement between students who learn using the ethnobiology-based interactive e-module and those who learn through conventional instruction; H2, there is a significant difference in posttest achievement among students with visual, auditory, and kinesthetic learning-style categories; and H3, there is a significant interaction between instructional treatment and learning-style category. The findings are expected to contribute empirical evidence on the value of contextualized digital teaching materials in biodiversity learning and to provide practical guidance for teachers in designing more inclusive and meaningful science instruction.

METHOD

Research approach

The current study employed a quantitative research approach with a posttest-only quasi-experimental design with a 2 × 3 factorial structure. This design involved two instructional conditions—an interactive ethnobiology-based e-module and conventional instruction—and three learning-style categories—visual, auditory, and kinesthetic—allowing it to examine both the main effects and the interaction effect. The design was categorized as quasi-experimental because the treatment was administered to intact school classes rather than to individually randomized students.

Time and location

The research was conducted from July to August 2025 at SMA Negeri 1 Indramayu. This location was chosen due to preliminary observations, indicating sub-optimal student scientific literacy and numeracy skills, as discussed in the introduction. The intervention was implemented over four meetings on biodiversity topics, followed by a posttest administered at the end of the treatment period.

Population and sample

The research population comprised all tenth-grade students at SMA Negeri 1 Indramayu for the academic year of 2025/2026. The sample was obtained using cluster random sampling at the class level, selecting two classes to serve as the research groups. Class X-4 was designated as the experimental class, which received treatment using the interactive e-module, and Class X-3 was designated as the control class, which received conventional instruction. The total sample consisted of 87 students, including 43 students in the experimental class and 44 students in the control class. The independent variable of the study was the interactive ethnobiology-based e-module accompanied by VAK-based multimodal learning activities. The outcome variable analyzed in the factorial ANOVA was the composite posttest achievement score derived from numeracy and scientific literacy items, and the moderator variable was the students' learning style. Randomization was conducted by drawing two classes from the available grade-X classes. After this, one class was assigned as the experimental group and the other as the control group. Because existing classes were maintained, full control of individual learner characteristics was not possible.

Research instruments

The research employed two primary instruments: a cognitive test and a learning style inventory. The cognitive test instrument consisted of 20 multiple-choice items covering numeracy and scientific literacy indicators in biodiversity content and was administered as a posttest. Before being used in the study, the instrument underwent expert judgment for content validity and empirical testing. The empirical testing included item validity, reliability, item difficulty, and discrimination power. Based on these results, the items were considered suitable for measuring the intended learning outcomes.

To improve methodological clarity, the instrument blueprint should indicate which items measured numeracy or scientific literacy. In this study, numeracy referred to students' ability to interpret quantitative information, use numerical representations, and draw construct tables, graphs, or numerical data. Scientific literacy refers to students' ability to explain scientific phenomena, interpret scientific evidence, and evaluate simple scientific investigations in the context of biodiversity.

Student learning styles (Visual, Auditory, Kinesthetic) were identified using a standardized learning style test available on the akupintar.id platform. This inventory categorized students to facilitate group discussions aligned with their respective learning preferences during the treatment phase.

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Data collection procedure

Data collection was carried out through a comprehensive three-stage procedure. The initial preparation stage involved compiling relevant literature, conducting preliminary interviews with the Biology teacher at SMA Negeri 1 Indramayu to confirm the existing learning issues, and formulating the final research problem. Subsequently, during the Development Stage, created and prepared all necessary research materials, which included the interactive ethnobiology-based e-module, the posttest instrument, the instrument blueprint, the student worksheet, and the administration tools for the learning style test. The final stage was the implementation stage, where the learning treatment was delivered over four meetings for both the experimental and control classes.

The experimental class began with the administration of the learning style test, followed by learning sessions using the interactive e-module and small-group discussions structured through multimodal visual, auditory, and kinesthetic activities. In contrast, the control class engaged in conventional learning using PowerPoint, standard textbooks, and instructional videos, followed by similar discussion procedures. Upon completion of the four meetings, the final posttest was administered simultaneously to both classes to measure the resulting differences in their numeracy and scientific literacy skills. The study was conducted in a school setting with the knowledge and permission of the school. Participation followed classroom procedures agreed upon by the school and the subject teacher.

Data analysis technique

The collected the data of posttest were analyzed to investigate the effect of the e-module treatment on students' achievement, considering the influence of learning style. The primary statistical technique employed was the Two-Way Analysis of Variance (ANOVA). This technique was chosen to allow the researchers to simultaneously test three main hypotheses: the main effect of the class factor (e-module vs. conventional), the main effect of the Learning Style factor (Visual, Auditory, Kinesthetic), and the Interaction effect between the two factors. A significance level (□) of 0.05 was used for all statistical tests.

Because the current analysis used a composite posttest score, the two-way ANOVA was applied to that combined outcome. However, numeracy and scientific literacy were also conceptually examined as separate indicators in the descriptive analysis. If future analyses or raw data are available, separate ANOVAs or MANOVA would provide stronger evidence for distinguishing the two constructs. Before the hypothesis test, the data were examined for normality and homogeneity assumptions. To strengthen reporting, effect size values such as partial eta squared should also be included for each main effect and interaction.

RESULT AND DISCUSSION

Results

The data analysis commenced with descriptive statistics to summarize the post-test scores on the composite achievement measure, which derived from numeracy and scientific literacy items across the experimental and control groups, categorized by student learning style. The descriptive results are presented in Table 1.

Table 1. Descriptive Analysis Results of Post-Test Scores

Class	Learning style	Mean	Std. Deviation	N
Experimental	Visual	77.73	9.045	11
	Auditory	74.00	8.216	5
	Kinesthetic	75.37	14.069	27
	Total	75.81	12.244	43
Control	Visual	61.56	14.109	16
	Auditory	52.08	12.515	12
	Kinesthetic	63.44	18.772	16
	Total	59.66	15.972	44
Total	Visual	68.15	14.554	27

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Class	Learning style	Mean	Std. Deviation	N
	Auditory	58.53	15.183	17
	Kinesthetic	70.93	16.806	43
	Total	67.64	16.333	87

Based on table 1, the total mean score for the experimental class (75.81) was substantially higher than that of the control class (59.66). Within the experimental group, students with a Visual learning style recorded the highest mean score (77.73), followed closely by Kinesthetics (75.37) and Auditory (74.00). This outcome suggests a relatively uniform level of achievement across all learning styles within the treatment group. The standard deviation (SD) for the experimental class are from 8.216 to 14.069, indicating a reasonably consistent spread of scores around the mean and a more homogeneous result. Conversely, the control class exhibited significantly lower mean scores across all learning styles, with the total mean score of 59.66. Moreover, the row labeled "Combined" refers to the descriptive summary of students from both classes and does not represent a separate treatment group.

Before conducting the Two-Way ANOVA to test the hypotheses, the data were examined for two key parametric assumptions: normality and homogeneity of variances. The results of the Shapiro-Wilk test for normality are presented in Table 2.

Table 2. Normality Test Results (Shapiro-Wilk)

Class	Statistic	df	Sig.
Experimental	.953	43	.076
Control	.962	44	.154

Table 2 shows that the significance value for the experimental class was 0.076 (>0.05) and the significance value for the control class was 0.154 (>0.05). Since both values were greater than 0.05, it concluded that the post-test scores for both groups were normally distributed. Subsequently, the Levene's Test was performed to assess the homogeneity of variances, as shown in Table 3.

Table 3. Test of Homogeneity of Variance (Levene's Test)

Source	Levene Statistic	df1	df2	Sig.
Based on Mean	3.322	1	85	0.72

The Levene's test yielded a significance value of 0.072 (> 0.05). This result indicates that the variances between the experimental and control groups were homogeneous, confirming that the assumption of homogeneity required for the Two-Way ANOVA was met. Hypothesis test with the parametric assumptions confirmed, which were tested using a Two-Way ANOVA. The full ANOVA results are presented in Table 4.

Table 4. Results of Two-Way ANOVA (Tests of Between-Subjects Effects)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6712.684[a]	5	1342.537	6.701	.000
Intercept	304621.515	1	304621.515	1520.361	.000
Class	4664.417	1	4664.417	23.280	.000
Learning style	486.153	2	243.076	1.213	.303
Class*Learning style	272.132	2	136.066	.679	.510
Error	16229.270	81	200.361		
Total	421025.000	87			
Corrected Total	22941.954	86			

a. R Squared = .293 (Adjusted R Squared = .249)

The inferential analysis yielded the following key findings: (1) Effect of the Class Factor: The analysis showed a statistically very significant difference in numeracy and scientific literacy skills

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between the experimental (e-module) and control (conventional) groups, F (1,81) = 23.280, p = 0.000. Since the p-value (0.000) was lower than the significance level (α = 0.05), the alternative hypothesis (Ha) was accepted. This result confirmed that the Class factor has a significant influence on differentiating student numeracy and scientific literacy outcomes. (2) Effect of the Learning Style Factor: The effect of the Learning Style factor was found to be statistically not significant, F(2,81) = 1.213, p = 0.303. As the p-value (0.303) was greater than α = 0.05, the null hypothesis (H0) was accepted. This suggests that learning style preference alone did not constitute a factor that significantly differentiated student numeracy and scientific literacy skills. (3) Interaction Effect: The interaction between the Class factor and the Learning Style factor was also found to be statistically not significant, F(2,81) = 0.679, p = 0.510. Since p> 0.05, the null hypothesis (H0) was accepted for the interaction. This crucial finding indicates that the effect of the e-module treatment was not dependent on the students' learning style, meaning the positive impact of the intervention was uniform across Visual, Auditory, and Kinesthetic.

Analysis of Numeracy and Scientific Literacy Indicators

The effectiveness of the ethnobiology-based interactive e-module accompanied by VAK-based multimodal activities was further examined by analyzing the descriptive percentages of numeracy and scientific literacy indicators, as illustrated in Figure 1.

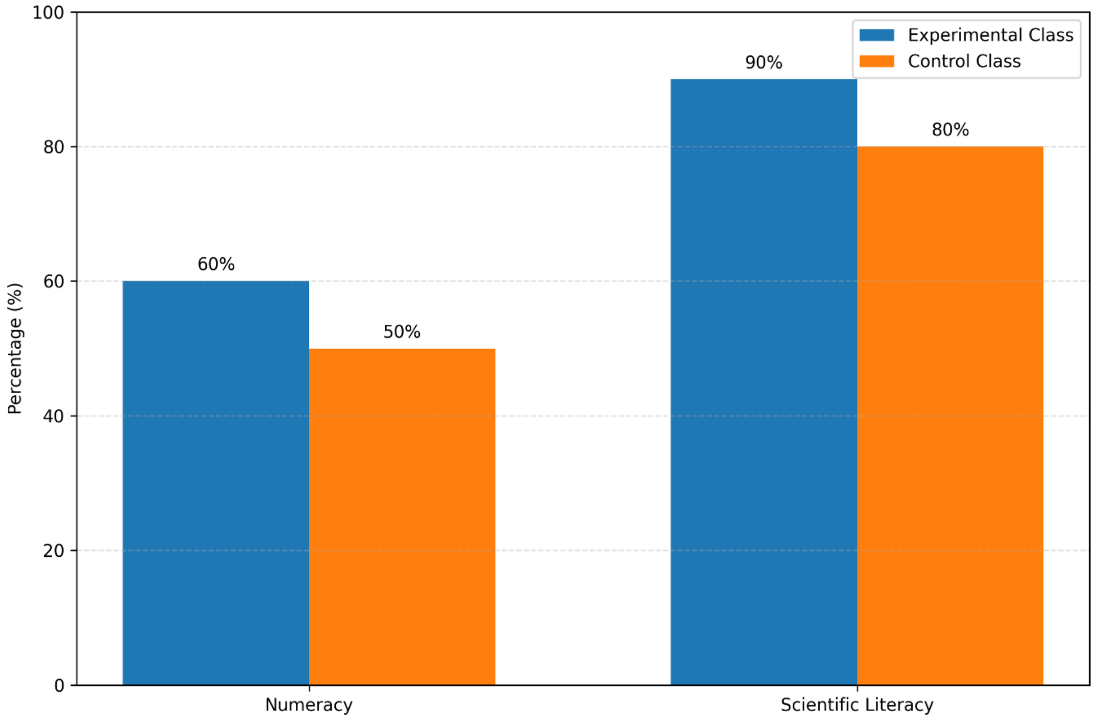

Figure 2. Presentase numeracy and scientific literacy indicators

Figure 1 shows that the experimental class obtained higher descriptive percentages than the control class on both reported indicator groups. Specifically, the numeracy indicator in the experimental class reached 60%, compared to only 50% in the control class. The difference was more pronounced for the scientific literacy indicator, where the experimental class achieved 90% against the control class's of 80%. These percentages should be interpreted as descriptive indicator summaries rather than as evidence of gain, because no pretest was administered in the present study. In addition, the manuscript should clarify the basis of percentage calculation, including the number of items representing each indicator and the categorization criteria used.

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Discussion

The findings indicate that students in the experimental class achieved higher posttest scores than the control class. This difference was supported by the two-way ANOVA results, which showed a significant main effect of instructional treatment. Within the context of the study, the use of an ethnobiology-based interactive e-module accompanied by multimodal visual, auditory, and kinesthetics activities was associated with higher achievement on the posttest measure than conventional instruction.

The most plausible explanation for this result lies in the design features of the e-module itself. First, the content was contextualized through local ethnobiological examples from the Indramayu area, making biodiversity concepts more concrete and meaningful for students. Second, the e-module presented the material through multiple representations, including text, images, interactive tasks, and guided activities, which likely supported students in engaging with the content more actively. Third, the embedded exercises required students to interpret information, relate concepts to real contexts, and respond to scientific questions rather than merely receive information passively. Compared with the control class, which learned through teacher explanation, PowerPoint, textbooks, and instructional videos, the experimental class experienced a more structured and interactive learning environment. For this reason, the discussion is better explained by the quality of multimodal and contextual instructional design than by the assumption that learning must be matched to a fixed learning-style category (Alim et al., 2025; Aslaksen et al., 2020; Grajcevci & Shala, 2025, 2025; J. Hattie & O'Leary, 2025; Hillmayr et al., 2020; Hussain et al., 2024; Nancekivell et al., 2021; Özeke et al., 2025).

The descriptive indicator analysis also suggests that the experimental class performed better on both numeracy and scientific literacy. In terms of numeracy, the e-module may have supported students in reading tables, graphs, and numerical information linked to biodiversity examples. In terms of scientific literacy, the contextual presentation may have helped students explain scientific phenomena, interpret evidence, and connect biodiversity concepts with local practices and environmental issues. These findings follows the previous studies reporting that interactive digital modules and contextual science learning support students' understanding and higher-order thinking (Alanoglu et al., 2025; Daryanes et al., 2023; Galimova et al., 2025; Hamidah et al., 2025; Songkram et al., 2023).

A second important finding is that the learning-style category did not show a statistically significant main effect, and there was no significant interaction between instructional treatment and learning-style category. This pattern suggests that the benefit of the e-module was relatively consistent across students categorized as visual, auditory, and kinesthetics. In other words, the instructional treatment appeared to work as a multimodal resource that provided access to the same content through more than one form of representation and activity. This result is more consistent with the argument that well-designed multimodal instruction support a broad range of learners than with the claim that instruction must be strictly differentiated according to learning styles (Aslaksen et al., 2020; Cuevas, 2015; Goyibova et al., 2025; Rahmanu & Molnár, 2024).

The absence of a significant interaction effect is important. It indicates that the treatment did not advantage only one learning-style category. Instead, the contextualized and multimodal structure of the e-module may have reduced dependence on any single preferred mode of learning. This interpretation is also consistent with prior literature suggesting that the instructional strategy, the relevance of the learning context, and the quality of material presentation may be more influential than learning-style categorization alone (J. A. C. Hattie & Donoghue, 2016; Oxman et al., 2024; Wininger et al., 2019). Overall, the discussion indicates that the main contribution of the intervention lies in its contextual, interactive, and multimodal features. These features are the most plausible drivers of the higher posttest scores observed in the experimental class.

However, the study has several limitations. First, it used a posttest-only design; therefore, the findings should be interpreted as differences in posttest achievement rather than direct evidence of improvement or gain. Second, the study was conducted in one school with two intact classes, which limits the generalizability of the findings to other contexts. Third, the factorial analysis used a composite posttest score, whereas numeracy and scientific literacy are conceptually distinct constructs; future studies should analyze them separately using independent ANOVAs or MANOVA when supported by the data structure. Fourth, the treatment period covered only four meetings, so the long-term retention of learning outcomes could not be examined. Finally, because learning-style categorization was based

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on a practical school-oriented inventory, the results should not be interpreted as definitive evidence about the broader validity of learning-style theory.

CONCLUSION

Based on the statistical findings, the study indicates that, in the context of grade-X students at SMA Negeri 1 Indramayu, the ethnobiology-based interactive e-module accompanied by VAK-based multimodal activities was associated with higher posttest achievement than conventional instruction. Also, the study found that the learning-style category was not significantly associated with the analyzed posttest score and did not significantly interact with instructional treatment. These results suggest that the contextual and multimodal quality of the e-module may be more important than learning-style categorization in supporting students' achievement in biodiversity learning. However, because the study was conducted in one school and used a posttest-only design, the conclusions should be interpreted within this specific context and should not be generalized too broadly. For further investigation, it is recommended that future studies investigate the long-term retention of numeracy and scientific literacy over a longer intervention period, analyze numeracy and scientific literacy as separate dependent variables, and explore the transferability of this ethnobiology-based, multi-modal approach to other science subjects and educational contexts.

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