Development E-Modules Integrated with Microlearning Video to Improve Students' Learning Outcomes and Critical Thinking on Environmental Change and Conservation Subject

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Abstract
This research focuses on developing an electronic module (e-module) integrated with microlearning videos focused on environmental change and conservation for 10th-grade high school students. The development process used a research and development approach based on the ADDIE model to ensure pedagogical excellence and systematic instructional design. The results of the expert validation phase, analyzed using the V Aiken index, yielded an average score of 0.85, categorizing the module as highly valid. Usability testing conducted with teachers and students showed average scores of 95.37% and 81.93%, respectively, placing the product in the "highly practical" category. Furthermore, the implementation of the e-module significantly improved students' learning outcomes and critical thinking skills, with a student graduation rate of 91.94% and critical thinking skills test results showing that the N -Gain scores in experimental class 1 at 0.46 and experimental class 2 at 0.59, both falling into the moderate category, indicating a fairly significant improvement in critical thinking skills. Meanwhile, the control class showed an average N-Gain score of 0.28, which falls into the low category. This indicates that there was no significant improvement in critical thinking skills in the control class. These findings suggest that e-modules integrated with microlearning videos serve as an effective cognitive stimulus that promotes improved learning outcomes and critical thinking skills among students regarding environmental change and conservation.

1. Introduction

The era of ever evolving technological advancement is marked by rapid technological developments across various fields, including education (Monib et al., 2024). In this era, various aspects of life including education, place a strong emphasis on mastering certain competencies to address these developments, known as 21st-century competencies, which encompass critical thinking, creativity, communication, and collaboration (Laar et al., 2020). One approach to addressing current technological advancements is to begin moving away from traditional learning methods. Traditional learning that relies on lecture-based methods does not motivate students to study and explore various topics in greater depth (Mohammed et al., 2018). Therefore, teachers need to create innovative and relevant learning experiences tailored to the characteristics of today's students. One way to do this is by integrating technology into the learning process. The integration of technology into learning drives a variety of innovative learning activities. This can positively correlate with learning outcomes and the development of various competencies while minimizing barriers in the learning process (Amelia et al., 2024). However, looking at the reality on the ground, the integration of technology in education has not yet been fully matched by improvements in the quality and reform of Indonesia's education system.

The current state of education in Indonesia can be illustrated by the results of surveys conducted by the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS). The 2022 PISA survey, which measures students' proficiency in mathematics, science, and literacy, showed that Indonesia ranked 69th out of 81 countries. Meanwhile, the TIMSS survey, which measures mathematical and scientific ability and understanding, showed that Indonesia's ranking has declined year over year (Alifiyah et al., 2025). The findings indicate that students are struggling with science and underscore the need for better learning experiences to help them improve their understanding of science (Faisal & Martin, 2019). Biology is a scientific discipline characterized by diverse concepts, complexity, abstract ideas, and meanings that require in-depth study. (Birzina, 2023). It serves as a foundational science for understanding the highly complex components of life. Consequently, mastering biology presents a challenge for students. Biology cannot be fully grasped through rote memorization, rather it requires innovative methods to develop analytical skills that enable a deeper understanding of its concepts (Birzina et al., 2021). One of the most

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important topics in biology that poses many difficulties is the subject of environmental change and conservation. According to Adams et al., (2020), mastery of the subject of environmental change and conservation is important to prepare students as future agents of change who understand the environment. One such challenge is that teachers often still rely on conventional teaching methods, which results in students failing to engage actively and being unable to gain a deep understanding of biological concepts (Akhmadkulovna, 2024). Furthermore, biology instruction often relies on learning materials containing inaccurate explanations and unengaging, monotonous presentations (Azizah & Alberida, 2021).

The results of this study aligns with the findings of a needs analysis that was conducted. Based on the results of the needs analysis, it shows that 87% of students require learning resources that are visually appealing and flexible meaning they can be used anywhere and anytime. Additionally, 78% of students prefer videos as a medium for delivering content, while 79% feel more focused when learning through short-duration videos. This was further confirmed through interviews with biology teachers at the school, who stated that students' primary learning resources are currently textbooks and other online references. Furthermore, the teachers acknowledged difficulties in delivering fact-based instruction due to limited learning resources, which is believed to be a factor contributing to students' difficulty in understanding biology material. The interviews also noted that students' critical thinking skills remain relatively low, with only an estimated 30–40% of students demonstrating these abilities during the learning process. Therefore, innovative teaching materials are needed to increase student engagement, which can have a positive impact on the development of 21st-century skills such as critical thinking.

An innovative tool for education that teachers may develop in order to overcome such problems is the electronic module (e-module). An e-module is a self-paced learning resource presented in digital format, equipped with various engaging tools and supported by video tutorials, animations, and audio presentations to enhance the quality of the learning experience for students (Suastrawan et al., 2021). As an interactive learning medium, e-modules systematically and engagingly present content, methods, assessments, and learning objectives. These modules include components such as methods, media, and assessment tools that are systematically organized and provided to students on a regular basis (Elvarita, et. al., 2020). While many e-modules are currently being developed by educators to support the learning process, many of them remain monotonous and non-interactive. Consequently, they fail to facilitate students in improving their learning outcomes or developing various competencies, such as critical thinking skills. Therefore, e-module developers need to integrate a learning strategy capable of enhancing the appeal of these resources to increase students' interest in biology learning, which can ultimately lead to improved learning outcomes and the development of critical thinking skills.

As an innovative learning strategy, microlearning can be integrated into the development of instructional materials such as e-modules. It can be described as an instructional technique that breaks down educational material into shorter and more concise bits (Söderberg, 2023). The use of microlearning techniques has the capacity to foster engagement, enhance information retention, and provide flexibility in the learning process. Moreover, it is compatible with the qualities of contemporary learners since they are familiar with quick and fragmented digital material (Zavodna et al., 2024). Microlearning can be integrated into various formats during the development of e-modules, including video. This format is the most commonly used in learning because video is considered the most effective medium for conveying large amounts of knowledge in a relatively short and limited time (Söderberg, 2023). According to Khong and Kabilan (2022), this aligns with neurocognitive principles, which suggest that the human brain tends to process and retain information more effectively when content is presented in small segments.

The various advantages of developing e-modules integrated with microlearning videos make them a potentially innovative solution. These e-modules can help teachers and students overcome various challenges in biology learning, particularly regarding the crucial topic of environmental change and conservation. Through these advantages, e-modules integrated with microlearning videos can enhance student learning outcomes, which positively impacts the development of 21st-century skills such as critical thinking. As one of the essential competencies in responding to the demands of modern education, critical thinking involves evaluating, analyzing, and synthesizing information appropriately to form arguments or draw conclusions based on empirical evidence (Reynders et al., 2020). Therefore, the development of these skills is crucial to supporting students' success in facing challenges and solving problems effectively (Khotimah, et. al., 2023). The rationale and urgency of this study are grounded in several previous studies. Some of the reference studies underpinning this research include the work by Kossen & Ooi, (2021) which found that microlearning videos are effective for learners in absorbing information with minimal cognitive load, this can facilitate deeper understanding, particularly in biology education. Furthermore, research by Choo et al., (2021) indicates that short microlearning videos can increase student engagement.

Previous research has widely demonstrated that the use of e-modules in learning can improve students' learning outcomes and critical thinking skills. Specifically, Pertiwi et al. (2024) demonstrated that the use of e-modules is capable of fostering students' critical thinking compared to the use of conventional media. These

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findings align with the results of Dewi and Kuswanto (2023), this study which confirms that the use of e-modules can increase critical thinking skills by providing various problem solving exercises and interactive activities to deepen their understanding. Furthermore, according to the findings of Logan et al. (2020) and Zhang & Jenkinson (2024), the use of e-modules offers several advantages, including providing real time feedback while tailoring the experience to teach student's distinct learning tempo, thereby empowers students to identify gaps in their knowledge, monitoring their own understanding and robustly promote the advancement of analytical thinking. However, so far little attention has been directed toward developing e-modules integrated with microlearning videos, particularly in biology instruction on environmental change and conservation. According to the results of Al-zahrani, (2024) research, it consistently shows that groups participating in microlearning-based instruction outperform traditional learning groups in various aspects, including academic achievement, knowledge retention, accessibility and the student's comprehensive learning experience. These results are also supported by Balasundaram et al., (2024) and Naser, (2024), who show that the application of microlearning effectively improves student learning outcomes. Hence, the objective of this research is to develop e-modules integrated with microlearning videos on the subject of environmental change and conservation to improve students' learning outcomes and critical thinking skills.

2. Method

A research and development (R&D) design is adopted in this study, with the primary objective of constructing an e-module integrated with microlearning videos for the biology topic of environmental change and conservation for 10th-grade high school students. To frame the research methodology, this study utilized the ADDIE approach, which systematically integrates five distinct phases: Analysis, Design, Development, Implementation and Evaluation. This framework serves as a primary benchmark for instructional design, offering a methodical process that secures outstanding pedagogical quality throughout development (Abuhassna et al., 2024). To ensure the continuous improvement of developing product, this study utilizes the ADDIE framework due to its iterative and systematic nature, which allows for formative evaluations throughout each phase (Sardin et al., 2025). The layout of this development model is displayed in Figure 1.

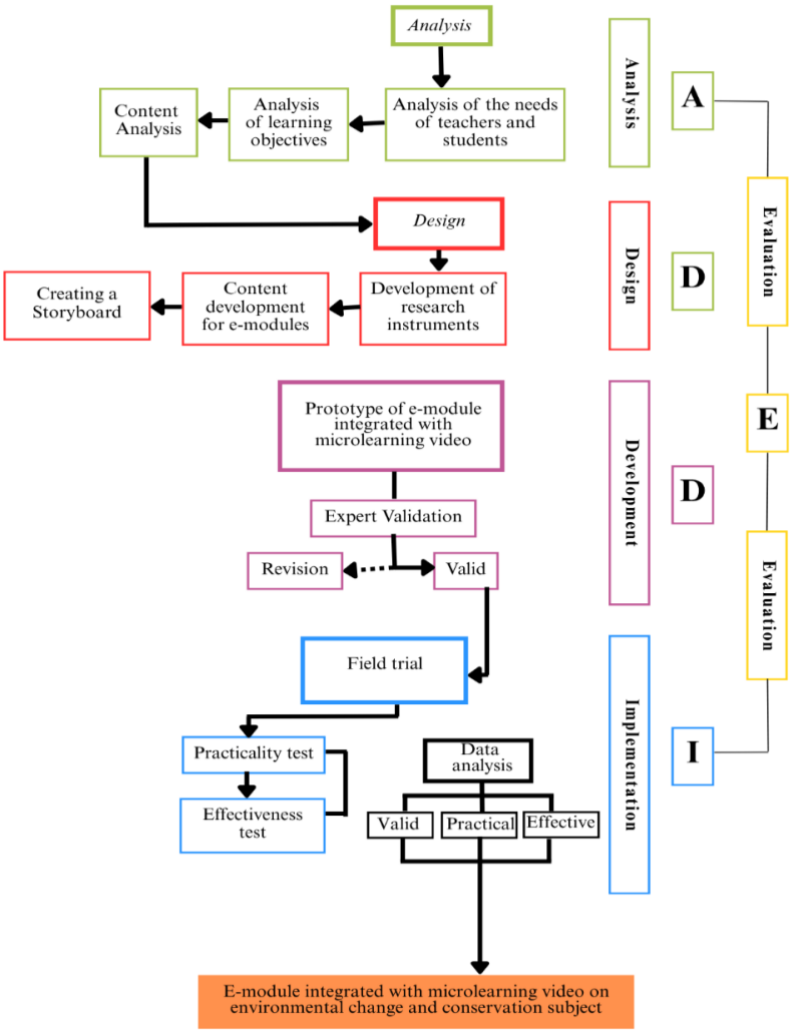

Figure 1. Stages of E-Module Integrated Microlearning Video Development Using ADDIE Method

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Based on Figure 1, the subjects of this study include validators, teachers, and students. The validators consist of three experts who assessed the validity of the e-module across several aspects. The teachers consist of three biology teachers, who assessed the practicality of the e-module integrated with microlearning video. The students come from three classes: X.1, X.2, and X.4, and their role is to determine the practicality and effectiveness of the e-modules integrated with microlearning videos.

To gather relevant data, an expert validation form is employed as a key instrument within this study, which was administered to three validators. The validation instrument utilizes a four-point scale: 1 (irrelevant), 2 (somewhat irrelevant), 3 (relevant), and 4 (highly relevant). The specific indicators used to measure the validity of the e-module integrated with microlearning videos according to Utaminingsih and Ellianawati (2025), as presented in Table 1.

Table 1. Validation Instrument for E-modules Integrated with Microlearning Videos by Expert Validators

Aspect	Indicator
Completeness E-Module	Attractive cover and title consistent with the content.
	Comprehensive introduction, including a table of contents and instructions for use.
	Completeness of videos, supporting links, and images.
Suitability of Presentation	Ease of e-module access
	User guidance page
	Systematic presentation
	Ease of sharing
	Instructional delivery
Usability	Ease of e-module operation
	Ease of media management
Graphic Quality	Consistency of menu layout
	Usage and consistency of font types and sizes
	E-module content design
Content Suitability	Material relevance and accuracy
	Up-to-datedness of material
Communicative	Facilitate understanding of information
Dialogical and Interactive	Motivating students
	Encourage learners to think critically

Based on Table 1, the validity of e-module was assessed based on several aspects including completeness of e-module, presentation feasibility, usability, graphic quality, content feasibility, communicativeness, dialogic and interactive qualities.

After undergoing a validation process by several expert, the expert validation questionnaire was analyzed using the V coefficient according to Aiken (1985). Aikens's V formula is presented in equation 1.

$$V = \frac{\sum S}{[n(c-1)]} \quad (1)$$

The final score V is calculated from the total sum of S. The value of S can be calculated using the formula r minus Io, where r is the score assigned by the validator and Io is the lowest validation score. This is then divided by n(c-1), where n is the number of evaluators and c is the highest validation score. Next, the results of the expert validators' assessments, which were analyzed in terms of the V coefficient, were classified into three categories: high validity, moderate validity, and low validity (Retnawati, 2015), as shown in Table 2.

Table 2. Evaluation Criteria Category

Coefficient V	Category
< 0.4	Low validity
0.4 ≤ v ≤ 0.8	Moderate validity
> 0.8	Highly valid

Based on the results in Table 2, a reliability test was then conducted based on the percentage of agreement among three experts, using the formula by Borich (1994), as presented in equation 2:

$$R = \left[1 - \frac{A-B}{A+B}\right] \quad (2)$$

A reliability test measures an instrument's dependability, if repeated administration under identical conditions produces stable and consistent data, the tool is considered reliable. The reliability value can be

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calculated using the formula in Equation 4, where R is the percentage of agreement, A is the score from the higher-ranking validator, and B is the score from the lower-ranking validator. The calculation results are then compared with the instrument reliability criteria based on the study by Wirayasa et al. (2020): a value under 0.20 shows very low agreement; 0.20 to 0.40 implies low agreement; 0.40 to 0.60 suggests moderate agreement; 0.60 to 0.80 demonstrated high agreement; 0.80 to 1.00 reflecting very high agreement.

After conducting validity and reliability tests, next the e-module integrated with microlearning videos was implemented and evaluated by teachers and students to assess its practicality. To assess the e-module's practicality, data were gathered using a four point scale questionnaire categorized as follows: 1 (irrelevant), 2 (somewhat irrelevant), 3 (relevant), and 4 (very relevant). Several questionnaire aspects and indicators for teachers were adapted from Rizal et al. (2024). A comprehensive overview of these indicators is provided in Table 3.

Table 3. Practicality Test Instrument for Teachers

Aspect	Indicator
Product Appropriateness	Media interface
	Content accuracy and engagement
	Media benefits
	Appropriateness of material and language
Usability of Presentation	Completeness of instructions
	Appropriateness of examples and exercises
Usability	The ease of using e-modules
	Facilitation of the learning process

Meanwhile, the aspects and indicators in the student questionnaire used to evaluate the practicality of the e-modules integrated with microlearning videos are outlined in Table 4.

Table 4. Practicality Test Instrument for Students

Aspect	Indicator
Product Appropriateness	Media interface
	Content accuracy and engagement
	Media benefits
	Presentation of the material
	Appropriateness of material and language
Usability of Presentation	Completeness of instructions
	Accuracy of examples and exercises
Usability	The ease of using e-modules
	Facilitation of the learning process

Next, the results of the teachers' and students' evaluations of the practicality of the e-modules integrated with microlearning videos were analyzed using the formula in equation 3:

$$P = \frac{\text{f}}{\text{N}} \text{ x } 100\% \quad (3)$$

The calculation of the final score (P) is achieved by dividing the obtained score (f) by the maximum attainable score (N). The resulting score is then used to classify the practicality of the e-module into five categories based on Utaminingsih and Ellianawati (2025): practicality test percentage score $0 < x \leq 20$ indicate not practical category; $20 < x \leq 40$ indicate less practical category; $40 < x \leq 60$ indicate practical enough category; $60 < x \leq 80$ indicate practical category; $80 < x \leq 100$ indicate very practical category.

Next, the effectiveness of the e-module integrated with microlearning videos was tested. To evaluate effectiveness of the e-module integrated with microlearning videos, this study analyzed both critical thinking abilities and student learning outcomes. The shift in learning outcomes was specifically measured using a pretest posttest approach applied to a single group. Meanwhile, improvements in critical thinking skills were analyzed using data from the pretest and posttest and calculated using the N-gain (normalized gain) formula. The N-gain formula is presented in equation 4:

$$Normalized\ Gain\ (N-Gain) = \frac{X_{Posttest} - X_{Pretest}}{X_{Max} - X_{Pretest}} \quad (4)$$

The N-Gain score can be calculated by subtracting the pretest score (X_Posttest) from the posttest score (X_Pretest) and then dividing the result by the difference between the maximum score (X_Max) and the posttest score (X_Pretest). The resulting N-Gain scores are then categorized according to Kartikasari et al., (2023): N-

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gain value less than 0.30 indicate low category; 0.30 ≤ (g) > 0.70 indicate medium category; N-gain value greater than 0.70 indicate high category.

3. Results and Discussion

3.1. Results

3.1.1. Characteristic E-Modul Integrated with Microlearning Video

3.1.1.1. Analysis

This analysis phase aims to identify potential causes of problems arising in the biology learning process in Grade 10. In this phase, the researcher conducted a needs analysis, an objectives analysis, and a content analysis. The needs analysis aims to identify and formulate the underlying problems that occur. The results of this analysis include facts, expectations, alternative solutions, and the formulation of strategies that will facilitate the selection of learning resources to be developed. Meanwhile, the objective analysis involves formulating learning objectives, while the content analysis is conducted to examine content based on the characteristics and needs of the students. Findings from the needs analysis conducted in Grade 10 indicate an urgent need to develop biology teaching materials that can stimulate students' enthusiasm in the biology learning process. Students today are familiar with the development of digital technology, but their mastery of this technology has not yet been fully and optimally integrated with learning content. To elevate the overall quality of educational processes, integrating technology into creation of learning materials has become absolutely essential.

3.1.1.2. Design

The design phase focuses on developing a solution to address the issues identified during the analysis phase. This phase focuses on designing an e-module with specifications such as an engaging structure and layout. The design includes various elements such as an attractive cover that illustrates the content of the e-module, an introduction, navigation buttons, content presented in the e-module, learning activities, a summary, reflection, and assessment.

Figure 2. Initial design of the E-module

As illustrated in Figure 2, the e-module is designed with an attractive layout and colour palette to capture learners' attention. In addition, it is designed to reflect the content of the e-module. The e-module also includes a table of contents page featuring engaging icons to help learners navigate the e-module. Additionally, the e-module design is crafted to incorporate distinctive e-module features such as Brainstorming, Microlearning Videos, Bukamata, Lensa Ekologi, and Ruang Eksplorasi.

3.1.1.3. Development

The e-module, which integrates microlearning videos, was developed using the Canva application in combination with various websites to support various activities in the learning process. Some of the applications or websites used in this e-module include: (1) YouTube, (2) Padlet, (3) Google Forms, (4) Google Sites, and (5) Wayground. The use of Canva as a graphic design platform is an effective strategic move. This platform offers advantages through comprehensive design features, such as a selection of modern fonts and a varied colour palette, thereby enhancing the aesthetics and quality of the learning materials. Additionally, Canva's capacity to integrate rich media, such as images and videos, is crucial for clarifying the concepts within the e-module.

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Another key advantage is the professional video editing feature available directly within Canva. This makes the process of editing microlearning videos much more practical since there is no longer a need to use additional applications. According to Figure 3, the microlearning videos in the e-module were designed and edited using Canva. Each microlearning video for each topic is less than 9 minutes long. The duration of microlearning videos is kept relatively short to account for learners' limited attention spans.

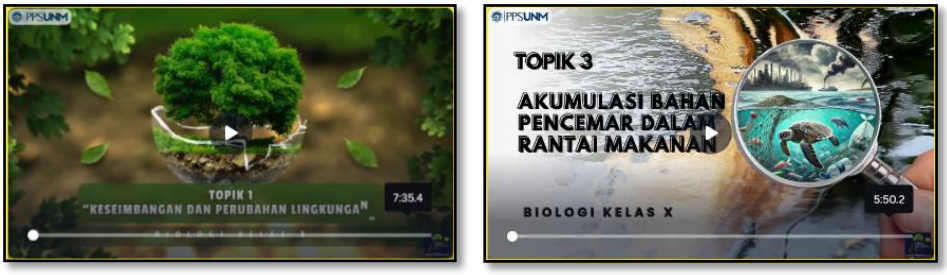

Figure 3. Microlearning Videos Edited using Canva

As illustrated in Figure 4 and 5, once the designing and constructing of the e-module integrated with microlearning videos is complete, the e-module must be validated before it is implemented in classroom instruction. In light of the validation findings, e-module requires several revisions, such as a cover design that does not yet fully represent the module's content, clearer numbering of subtopics, image captions and links to image or video sources, clearer instructions for each activity within the e-module, and making the quiz easier to access such as by providing a link or QR code. These revisions were made to enhance the accessibility of e-module for students.

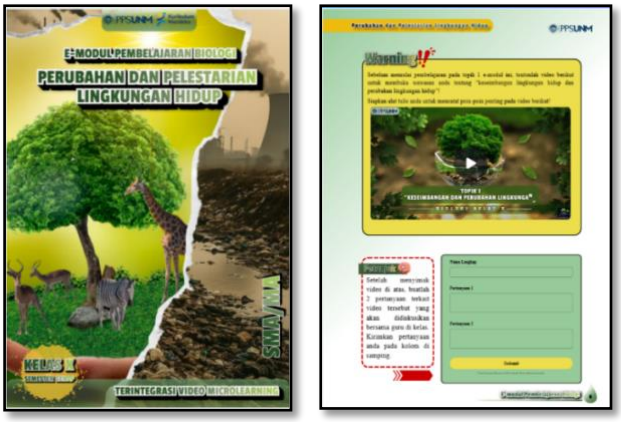

Figure 4. Pre-revision Version of the E-module

Figure 5. Post-revision Version of the E-module

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3.1.2. Results of the Validity Test for E-Modul Integrated with Microlearning Videos

In this study, the integrated e-module was validated by three experts to ensure its validity prior to limited field testing. The validation process encompassed several evaluative aspects, with the degree of validity being analyzed using the Aiken's V-index. The outcomes of the validity assessment coefficient analysis, representing the expert agreement index as measured by Aiken's V, are presented in Table 5.

Table 5. Validity Analysis of E-Module Integrated with Microlearning Videos Using Aiken's Index

Aspect	Total Validity Item Score	V	Category	R	Category
Completeness E-Module	8.67	0.87	Valid	0.89	Very high
Presentation Feasibility	8.11	0.81	Valid	0.92	Very high
Usability	2.56	0.85	Valid	0.86	Very high
Graphic Quality	9.22	0.84	Valid	0.89	Very high
Content Feasibility	5	0.83	Valid	0.88	Very high
Communicativeness	1.56	0.78	Valid	0.93	Very high
Dialogic and Interactive Qualities	1.89	0.94	Valid	0.93	Very high
Average	5.29	0.85	Valid	0,9	Very high

Based on Table 5, all assessed aspects fall within the valid category. The e-module's completeness aspect received an Aiken's V index of 0.87. The presentation suitability aspect received an Aiken's V index of 0.81. The ease-of-use aspect received an Aiken's V index of 0.85. The graphical aspect received an Aiken's V index of 0.84. The content suitability aspect received an Aiken's V index of 0.83. The communicative aspect received an Aiken's V index of 0.78. The dialogic and interactive aspect received an Aiken's V index of 0.94. The overall average validity index was 0.85, indicating that the e-module integrated with microlearning videos is suitable to proceed to the limited pilot test phase. In addition, Table 5 shows that the reliability scores for each aspect fall within the "very high" category.

3.1.3. Results of the Practicality Test for the E-Module Integrated with Microlearning Videos

Questionnaires were distributed to both teachers and students to measure the practicality of the e-module integrated with microlearning videos. The teacher evaluation was conducted by three biology teachers. This evaluation instrument comprised 27 items focusing on product quality, material presentation, and the functional utilization of the integrated e-module. The teachers' responses concerning the practicality of the developed module are summarized in Table 6.

Table 6. Result Teachers' Responses to the Practicality of E-Modules Integrated with Microlearning Videos

Aspect	Number of Statement	F	N	P (%)	Category
Product Quality	15	171	180	95	Very practical
Material Presentation	6	69	72	95.83	Very practical
Utilization	6	69	72	95.83	Very practical
Total Score (∑F)	309				
Maximum Ideal Score (∑N)	324				
Practicality Percentage (P)	95.37%				Very practical

Analysis of the teacher response data in Table 6 yielded an average score of 95.37%, placing the e-module in the 'very practical' category. The practicality of the integrated e-module was further evaluated by students during the learning process. This assessment involved students from classes X1 and X2. The limited pilot phase was conducted specifically to identify potential technical and pedagogical challenges, the results of which provided a critical basis for refining the e-module prior to the operational field trial. Students' perceptions and feedback regarding the practicality of the developed module are summarized in Table 7.

Table 7. Result Students' Responses to the Practicality of E-Modules Integrated with Microlearning Video

Aspect	Number of Statement	F	N	P (%)	Category
Product Quality	17	3460	4216	82.07%	Very practical
Material Presentation	5	1011	1240	81.53%	Very practical
Utilization	5	1015	1240	81.85%	Very practical
Total Score (∑F)	5486				
Maximum Ideal Score (∑N)	6696				
Practicality Percentage (P)	81.93%				Very practical

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The student response data detailed in Table 7 reveals that the e-module secured a mean practicality rating of 81.93%, which qualifies it for the 'very practical' classification.

3.1.4. Results of the Effectiveness Test for the E-Module Integrated with Microlearning Videos

The effectiveness of the integrated e-module is demonstrated by the significant advancement in both student learning outcomes and critical thinking skills following its implementation in biology instruction. The impact on general learning outcomes was determined based on assessment results from classes X.1 and X.2. Furthermore, the e-module's effectiveness in fostering advanced critical thinking abilities was evaluated by comparing the test results of the experimental groups (classes X.1 and X.2) with those of the control group (class X.4).

The pretest was administered to assess students' initial learning outcomes and critical thinking skills prior to the intervention. Conversely, the posttest was conducted to measure these same variables subsequent to the deployment of the integrated e-module in biology instruction. A comparative analysis of students' learning outcomes before and after the use of the module integrated with microlearning video is comprehensively in Table 8.

Table 8. Results of the Students' Learning Outcomes Score Analysis

Statistics	Score	
	Pretest	Posttest
Number of students	62	62
Average	47.85	82.47
Highest score	80	100
Lowest score	20	60
Number of students who passed	3	57
Number of students who failed	59	5

Table 8 reveals that the average student score increased significantly from 47.85 on the pretest to 82.47 on the posttest. Pretest scores ranged from 20 to 80, whereas posttest scores showed a marked improvement, ranging from 60 to 100. Based on these results, 57 out of 62 students successfully achieved the minimum passing grade of 70, resulting in a classical completion rate of 91.94%. According to the effectiveness criteria, this percentage is classified as effective, as it exceeds the established threshold of ≥80%. These findings demonstrate a substantial improvement in student learning outcomes following the implementation of the integrated e-module.

Beyond the enhancement of learning outcomes, the effectiveness of the e-module integrated with video microlearning was also evaluated through the advancement of students' critical thinking abilities. The assessment data, derived from a comparison of pretest and posttest scores, are detailed in Table 9. Table 9 illustrates a notable improvement in students' critical thinking skills across all groups, as substantiated by the shift observed between the pretest and posttest metrics. For the participants in experimental Class 1, the average score rose from 7.77 to 13.37, while Experimental Class 2 demonstrated a more substantial increase, with average scores climbing from 4.69 to 13.75. On the other hand, a less pronounced growth was observed in the control class, where the mean score shifted from 5.00 to 9.13.

Table 9. Results of the Critical Thinking Skills Score Analysis

Statistics	Experimental Group 1		Experimental Group 2		Control group	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Maximum ideal score	20	20	20	20	20	20
Minimum ideal score	0	0	0	0	0	0
Maximum empirical score	13	20	13	20	14	19
Minimum empirical score	2	11	2	9	0	4
Average score	7.77	13.37	4.69	13.75	5	9.13

Table 10 shows that the average N-Gain values for experimental classes 1 and 2 were 0.45 and 0.59, respectively, which fall into the moderate category, with standard deviations of 0.16 and 0.2, respectively. Conversely, an N-Gain score of 0.28 was recorded for the control class, placing it within the low classification, accompanied by a standard deviation of 0.21.

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Table 10. Analysis of Normalized Gain (N-Gain) in Students' Critical Thinking Skills

Class	N-Gain	Interpretation		Standard Deviation
Experimental 1	0.46	0.30 ≤ (g) > 0.70	Medium	0.16
Experimental 2	0.59	0.30 ≤ (g) > 0.70	Medium	0.2
Control	0.28	(g) < 0.30	Low	0.21

3.2. Discussion

The framework utilized to guide the development process in this research and development (R&D) project is the ADDIE model. The model ensures a structured approach to the production of e-module by meticulously covering the stages of analysis, design, development, implementation and evaluation. Video-integrated microlearning e-modules serve as a strategic solution to address the issues identified during the analysis phase. As technology-based interactive instructional materials, e-modules can provide a dynamic learning experience compared to using textbooks or printed modules. To successfully elevate students' critical thinking abilities, integrating a diverse mix of media including text, graphics, audio, video and animation has proven to be highly efficient. This aligns with the findings of (Zhou, 2024), which indicate that interactive learning resources enriched with multimedia are effective in fostering deep understanding among students. This finding aligns with the research conducted by Bucheli et al. (2024) who state that multimedia representations in instructional materials can foster students' critical thinking abilities. Thus, e-modules are considered an appropriate solution to meet students' needs for interactive learning resources in today's educational landscape.

This e-module also incorporates microlearning videos for each topic to make the learning process more efficient. Microlearning videos, as an interactive learning medium that are short in duration and focus on a single specific topic, are considered capable of reducing the cognitive load of learners, who currently face a high volume of information. Additionally, the integration of microlearning videos into the e-module can help visualize various abstract and difficult-to-understand concepts in the material on environmental change and conservation. The combination of various media in microlearning videos can enhance student retention. A similar conclusion was reached by Korstange et al., (2020) who demonstrated that microlearning can address students' cognitive overload, and Kossen and Ooi, (2021) who noted that microlearning can make learning more engaging for students by reducing the volume of information they receive.

The e-module integrated with microlearning videos that was developed has met the validity criteria, as confirmed by three experts. The assessment by these three experts confirmed that several evaluated aspects such as the completeness of the e-module, the appropriateness of its presentation, ease of use, graphics, content appropriateness, and its communicative, dialogic, and interactive nature have met the validity criteria. Overall, this validation indicates that the integrated video microlearning e-module is suitable for use in classroom learning. This is further substantiated by the empirical evidence presented by Pratama et al., (2018), who stated that biology e-modules that have been developed and meet validity criteria can be implemented in the classroom learning process. This is also consistent with Kholisah and Susanto (2024) who demonstrated that e-modules that have undergone the validation stage can outperform printed e-modules in strengthening students' understanding.

In addition to its validity, the e-module integrated with microlearning videos resulted in outstanding practicality ratings based on evaluations by teachers and students. According to teachers' responses regarding the practicality of the e-module, the practicality rate was 95.37%, which falls into the "very practical" category. The use of e-modules enables teachers to conduct lessons more efficiently, as the integration of various media within the e-modules facilitates the contextualization of materials on environmental change and conservation. Concurrently, feedback gathered from students reflected an 81,93% practicality rate, thereby aligning the e-module with the "very practical" designation. These findings suggest that e-modules integrated with microlearning videos are engaging, interactive, and help students understand the material on environmental change and conservation. Furthermore, e-module compatibility with diverse digital platforms grants students the flexibility to engage with the learning materials without time or location constraints. Closely align with Kumar et al., (2023) who state that the use of e-modules in the learning process can help improve students' learning autonomy, and Muir et al., (2022), who argue that embedding multimedia within e-modules fosters meaningful interactions between teacher and student engagement through the instructional process.

Apart from validity and practicality, the most important aspect is that e-modules integrated with microlearning videos not only streamlines the learning experience but also drives significant improvement in both students' critical thinking abilities and overall learning outcomes. This is demonstrated by the results of the analysis of the e-module's effectiveness. The results of the analysis of improvements in student learning outcomes were measured based on the percentage of students who achieved the minimum passing criteria in classes X.1 and X.2. Based on the analysis of learning outcomes, it was observed that during the pretest, only 3 students achieved the minimum passing criteria score, while 59 students did not meet the minimum passing criteria. Meanwhile, the posttest showed different results: 57 students achieved the minimum passing criteria, while only 3 students did not. This indicates that the e-module integrated with microlearning videos has proven

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effective in driving better student learning outcomes. These findings align with the research by Fidiastuti et al., (2021) which states that the use of e-modules can contribute to improving students' learning outcomes in biology. This is because e-modules not only present real-world examples with engaging visuals but also help students visualize the events or phenomena being studied. These findings are further supported by the research of Delita et al. (2022), which demonstrates that the implementation of e-modules effectively enhances student learning outcomes because e-modules are designed based on student characteristics, the principles of active and interactive learning, and the integration of technology. E-modules can also help clarify concepts more effectively because they are presented contextually and in visual, audio, or audiovisual formats.

To evaluate improvement in critical thinking abilities, data from the pretest and posttest were examined utilizing the N-Gain formula. The analysis of critical thinking skills was carried out in three classes: classes X.1 and X.2 as experimental classes and class X.4 as the control class. The analysis results indicate that the average N-Gain score for experimental class 1 was 0.46 and for experimental class 2 was 0.59, both falling into the moderate category. This indicates substantial improvement in critical thinking skills from the pretest to the posttest. This demonstrates that biology instruction using an e-module integrated with microlearning videos is effective in enhancing students' critical thinking skills. Meanwhile, the control class showed an average N-Gain score of 0.28, which falls into the low category. This indicates that no significant improvement in critical thinking skills occurred in the control class. These findings align with previous research conducted by Dermawan et al., (2025) which demonstrated that the use of e-modules in learning is effective in enhancing students' critical thinking skills. Through structured content presentation and interactive visual design, e-modules can serve as cognitive stimuli that facilitate learners' active engagement in the learning process. This enables learners to analyze, evaluate, and connect information more critically.

Furthermore, the findings of this study are supported by several previous studies, including those by Aristin et al., (2023) and Dahal et al., (2023), which indicate that e-modules designed with engaging visual elements can enhance critical thinking skills. These findings indicate a positive correlation between the use of interactive features and the strengthening of critical thinking skills, consistent with the research by Sahraie et al., (2024) which demonstrated that utilizing adaptive quizzes and dynamic simulation substantially elevates learners' critical thinking capacities. This outcome directly resonates with the core objective of the current research, which emphasizes fostering analytical proficiency through interactive e-modules. Nevertheless, there is a difference in perspective with the research by Sujanem dan Suwindra (2023), which states that visual features are not the primary factor, but rather the direct involvement of students in the learning process. Through the integration of these two aspects, this study contributes by fostering active learner involvement through interactive components to develop critical competencies, while simultaneously broadening the theoretical understanding of how visual and interactive elements synergize.

3.3. Implications

The implications of this study are that it can act as a guideline for other researchers in the development of technology-based instructional materials. The e-module integrated with microlearning videos, as the product of this study, can serve as a new innovation in biology education, providing an interactive, flexible, and technology-based learning resource. Through this e-module, teachers can enrich students' learning resources while also gaining additional references on how to integrate various digital media into instruction. Furthermore, the contextual examples of environmental issues included in this e-module can enhance students' awareness of environmental challenges.

3.4. Limitations

The limitations of this research are that the development of e-modules integrated with microlearning videos was limited to topics related to environmental change and conservation. Additionally, this study was conducted as a small-scale pilot test. Future research is expected to develop e-modules integrated with microlearning videos for other biology topics and even other subjects, and to conduct pilot tests on a larger scale.

4. Conclusion

The development and implementation of the e-module integrated with microlearning videos on the topic of environmental change and conservation have proven to be highly effective in enhancing both learning outcomes and critical thinking skills among 10th-grade students. The research confirms that the product meets the criteria for high validity, practicality, and effectiveness, significantly outperforming conventional instruction methods in fostering analytical proficiency. Scientifically, this study highlights the strategic importance of microlearning in reducing cognitive load while facilitating deep conceptual understanding through interactive visual stimuli. These results suggest that integrating technology-driven instructional materials into the biology curriculum is a vital step toward meeting the imperatives of 21st-century pedagogy and preparing students to address complex environmental challenges proactively.

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Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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