

The Use of Interactive E-Modules for Students' Critical Thinking Skills in Biology Instruction (2022–2026): A Systematic Literature Review

Penggunaan E-Modul Interaktif dalam Keterampilan Berpikir kritis Siswa pada Pembelajaran Biologi (2022-2026): *Systematic Literature Review*

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Abstract	Article Information	
<i>Technological and curricular advancements necessitate a student-centered approach to biology education that optimizes critical thinking skills. This study aims to provide a systematic overview of publication trends, learning models employed, platforms or software used, forms of interactivity, and key findings regarding the use of interactive e-modules to enhance students' critical thinking in biology. A Systematic Literature Review method was employed, adhering to PRISMA guidelines. Literature searches were conducted via Google Scholar using the "Publish or Perish" application for the period of 2022–2026, followed by bibliometric analysis using VOSviewer software. The selection process yielded 22 articles that met the inclusion criteria for further analysis. The results indicate a significant rise in publication trends, particularly between 2025 and 2026. Problem-Based Learning emerged as the most frequently utilized learning model. The development of interactive e-modules incorporates various tools and integrates artificial intelligence, featuring dynamic multimedia, interactive navigation, and real-time feedback-based evaluations. Interactive e-modules have proven effective in facilitating critical thinking indicators such as analysis, inference, and evaluation especially when addressing abstract biological concepts. Therefore, integrating problem-based learning models with interactive e-modules featuring dynamic multimedia is highly recommended for biology instruction to move away from conventional methods and foster student learning autonomy.</i>	Keywords: Biology learning; critical thinking; interactive e-module; Systematic Literature Review (SLR)	Kata kunci: Berpikir kritis; e-modul interaktif; pembelajaran biologi; Systematic Literature Review (SLR)
Perkembangan teknologi dan kurikulum menuntut pembelajaran biologi yang berpusat pada siswa seras mampu mengoptimalkan keterampilan berpikir kritis. Penelitian ini bertujuan untuk memberikan gambaran sistematis mengenai tren publikasi, model pembelajaran yang digunakan, platform atau software, bentuk interaktivitas, serta temuan utama terkait penggunaan e-modul interaktif dalam peningkatan berpikir kritis siswa pada mata pelajaran biologi. Penelitian ini menggunakan metode <i>Systematic Literature Review</i> , mengikuti prosedur PRISMA. Pencarian literatur dilakukan melalui basis data <i>Google Scholar</i> menggunakan aplikasi <i>Publish or Perish</i> dalam rentang tahun 2022 hingga 2026, serta dianalisis secara bibliometrik menggunakan perangkat lunak <i>VOSviewer</i> . Berdasarkan tahapan seleksi, diperoleh 22 artikel yang memenuhi kriteria inklusi untuk dianalisis lebih lanjut. Hasil analisis menunjukkan bahwa tren publikasi penelitian mengalami peningkatan signifikan, khususnya tahun 2025 hingga 2026. Model pembelajaran paling sering digunakan adalah <i>Problem Based Learning</i> . Pengembangan e-modul interaktif memanfaatkan berbagai perangkat dan integrasi teknologi kecerdasan buatan yang dilengkapi dengan multimedia dinamis, navigasi interaktif, serta evaluasi berbasis <i>real-time feedback</i> . E-modul interaktif terbukti efektif dalam memfasilitasi indikator berpikir kritis siswa seperti analisis, inferensi, dan evaluasi, terutama pada materi biologi abstrak. Oleh karena itu, integrasi model pembelajaran berbasis masalah dengan e-modul interaktif dengan multimedia dinamis sangat direkomendasikan untuk diterapkan dalam pembelajaran biologi guna mengurangi metode konvensional dan meningkatkan kemandirian belajar siswa.	History Manuscript received : 19/10/2026 Revised : 28/10/2026 Accepted : 29/10/2026 Published : 31/10/2026	

A. INTRODUCTION

The evolution of the times influences the development of learning media, which serves as a support for enhancing the effectiveness and efficiency of the learning process (Mahmud et al., 2025). The effectiveness of using such media relies heavily on the teacher's ability to utilize and activate it, as well as on the teacher's role in providing information or instructional materials (Febriani et al., 2023). Learning media should offer engaging experiences that cater to the diverse needs of individual learners, given that every student possesses different abilities and characteristics (Rakhman et al., 2024). Consequently, e-modules represent an effective type of learning medium for supporting and improving the learning process (Jafnihirda et al., 2023).

An e-module is a collection of digital learning media systematically designed to meet the needs of independent study. It incorporates animations, audio presentations, and video tutorials to make the learning experience more engaging for students (Mahmud et al., 2025). E-modules are also designed to help students grasp concepts and develop skills through interactive content, which includes the use of the-matic (trigger) questions, video links, and up-to-date information relevant to biology subject matter (Suryani et al., 2024; Wulandari et al., 2023). In biology education, students sometimes struggle to understand abstract concepts (Tasyari et al., 2021). The use of interactive e-modules can help visualize these concepts more effectively, thereby facilitating student comprehension (Mahmud et al., 2025). Furthermore, e-modules can enhance student interest in the learning process, foster greater interactivity, and allow for access anytime and anywhere (Pramudita & Rahayu, 2024). As a form of self-directed learning material—specifically digital learning media—e-modules can enrich the student learning experience and, in turn, improve students' critical thinking skills (Rismayanti & Sukirwan, 2022).

Educational demands require students to possess various 21st-century skills, including critical thinking and problem-solving abilities (Rosidi et al., 2023). Critical thinking skills encompass the capacity to solve problems by identifying the causes of an event, evaluating them logically, determining solutions, and drawing conclusions (Fitriani et al., 2024). Critical thinking enables the systematic analysis of data or information, applying logic to the examination of facts or evidence (Agnafia, 2019). Therefore, effective instruction must actively engage students, allowing them to develop critical thinking skills while understanding biology as a dynamic and applicable science (Restudila et al., 2025).

The use of technology in biology instruction has yet to be fully optimized. Several studies indicate that the learning process still faces limitations regarding the integration of digital media that fosters active student engagement (Fatma et al., 2025). Sarianti et al., (2026) note that biology instruction in schools remains dominated by conventional methods—such as lectures and the use of static media like textbooks and presentation slides which often leads to passive student participation. Such conditions can result in students failing to engage actively in the learning process. Furthermore, Puspitaningrum et al., (2025) point out that the suboptimal use of technology in school-based instruction can hinder the development of students' critical thinking skills, which in turn may affect their ability to solve problems effectively.

Although there has been a significant number of publications regarding e-modules in Indonesia over the past five years, most have focused on technical aspects such as product development, expert validation, and effectiveness in terms of learning outcomes. Meanwhile, research that systematically maps broader developments including research focus, methodologies employed, fields of study, and the extent to which e-module development supports 21st-century skills remains limited (Rizara et al., 2026). Previous literature reviews have examined the use of e-modules in education. Kumalasari et al., (2025) analyzed 30 articles, demonstrating that interactive e-modules are effective in enhancing mathematical problem-solving skills; however, their study was confined to mathematics education and did

not address critical thinking skills or the context of biology education. In the field of biology, Fatma et al., (2025) reviewed ten articles on biology e-modules, yet their focus was limited to general validity, practicality, and effectiveness, lacking a systematic procedural framework. Rahmadhani & Syamsyurizal, (2026) conducted a systematic literature review (SLR) of 24 articles concerning interactive digital media and critical thinking; however, as their scope encompassed various media types and all educational levels, only four studies focused on e-modules, and the specific platforms and forms of interactivity were not analyzed. Consequently, there is currently no systematic study that specifically maps publication trends, learning models, platforms, and forms of interactivity in e-modules, nor one that synthesizes key findings regarding the role of interactive e-modules in fostering critical thinking skills within biology education. This study was conducted to address this gap.

Based on the description above, there is a need for a study that provides a systematic overview of the development of research regarding the use of interactive e-modules for fostering critical thinking skills in biology education. Therefore, this study employs a Systematic Literature Review (SLR) approach to identify, examine, and synthesize findings from previous research on the use of interactive e-modules in biology instruction. Specifically, the objectives of this study are as follows:

1. To determine publication trends in research concerning the use of interactive e-modules to enhance students' critical thinking skills in biology education over the last five years.
2. To identify the learning models or approaches most frequently employed in the development of interactive e-modules for biology education.
3. To identify the platforms or software used, as well as the types of interactivity incorporated into these e-modules.
4. To ascertain key findings and essential information from the reviewed articles that can serve as a reference for the development of interactive biology e-modules aimed at improving critical thinking skills.
- 5.

B. METHOD

This study employs the Systematic Literature Review (SLR) method. An SLR is a research method and process conducted systematically to identify, critically appraise, collect, and analyze data from relevant studies. The SLR method aims to identify all empirical evidence that meets predetermined inclusion criteria in order to address specific research questions. (Snyder, 2019).

Research questions (RQs) are formulated to define the scope of a study, ensuring that the research is conducted with a clearer direction and focus. These research questions were developed to address specific needs related to the chosen topic, as follows:

- RQ1 : What are the trends in research publications concerning interactive e-modules for enhancing students' critical thinking skills in biology education over the last five years?
- RQ2 : Which learning models or approaches are most frequently employed in the development of interactive e-modules for biology education?
- RQ3 : What platforms or software, and what forms of interactivity, are utilized in these e-modules?
- RQ4 : What are the key findings and significant insights derived from the reviewed articles that can serve as a reference for developing interactive biology e-modules aimed at improving critical thinking skills?
- RQ1–RQ4 were addressed through the extraction and synthesis of data from selected articles. Keyword co-occurrence analysis was employed to support RQ2 and RQ3; however, it was not used to assess learning effectiveness.

A literature search was conducted in a single database, Google Scholar, using the "Publish or Perish" software on September 27, 2026. The search utilized the keywords "interactive e-module," "critical thinking," and "biology," covering the period from 2022 to 2026. For 2026, only articles published and indexed in Google Scholar up to the search date (September 27, 2026) were included; articles published or indexed after this date were excluded. The search yielded a maximum of 328 articles. These results were exported in RIS and CSV formats and subsequently imported into a reference manager (Mendeley) to organize the retrieved articles. Duplicates were removed using Mendeley's built-in duplicate-detection feature, followed by a manual verification of titles, authors, publication years, and DOIs; in cases of duplication, only the copy with the most complete metadata was retained. Furthermore, the data were visualized using VOSviewer software to present the findings in a clearer, more engaging, and communicative manner. The article selection process in this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021) which consist of four primary stages: identification, screening, eligibility, and inclusion. The researchers utilized the PRISMA 2020 framework to carry out the inclusion and exclusion process.

Inclusion and exclusion criteria were applied throughout the data collection and selection process. An article was included—or passed the selection stage—if it met all of the following criteria: (1) it is a journal article published between 2022 and 2026; (2) the full text is accessible; (3) it originates from a journal (indexed in Google Scholar); (4) it discusses interactive e-modules; (5) it relates to biology education at the secondary (junior and senior high school/vocational school) or higher education level; (6) it addresses critical thinking skills within these educational levels; (7) it is relevant to the research title/keywords; and (8) it is written in Indonesian. Conversely, an article was excluded if: (1) it is a book, a citation, a document (PDF or HTML), or was published before 2022; (2) the full text is inaccessible; (3) it is an item from an institutional repository; (4) it does not pertain to interactive e-modules; (5) it is unrelated to biology education at the secondary or higher education level; (6) it does not address critical thinking skills at these educational levels; (7) it is irrelevant to the research title/keywords; or (8) it is written in English. A total of 328 articles were identified during the initial data collection phase as being relevant to the objectives of this literature review. Subsequently, to align with the objectives of the literature review in this study, a screening process and an assessment of data eligibility were conducted for the identified articles (Rachmadhani & Kamalia, 2023). As a final result of these stages, 22 articles were obtained that met the established criteria.

As shown in Figure 1 below, during the identification phase, a search conducted via Publish or Perish on Google Scholar yielded 328 articles. No duplicate records were found ($n = 0$); therefore, all 328 articles proceeded to the screening phase. In the screening phase, the articles were evaluated based on their type, title, and abstract. A total of 55 articles were excluded because they were not identifiable as journal articles for instance, they were books or documents consisting solely of citations. (Note: Files in PDF or HTML format were excluded based on the nature of the source, not the file format itself.) This left 273 journal articles. All of these articles were successfully retrieved in full-text format ($n = 0$). The next stage involved an eligibility assessment of the 273 articles, focusing on three thematic aspects: interactive e-modules, biology education, and critical thinking skills. This assessment resulted in the exclusion of 251 articles: 185 were outside the context of biology education, 44 were irrelevant to the research title or keywords, 8 did not address critical thinking skills, 8 were repository documents, 5 were inaccessible, and 1 did not pertain to interactive e-modules. Ultimately, 22 articles were selected for inclusion, as they were relevant, met all pre-established inclusion criteria, and successfully passed every stage of the selection process; these are the articles that were subjected to further analysis in this study.

The sequence of the inclusion and exclusion process carried out in this Systematic Literature Review (SLR) is presented in the following flowchart:

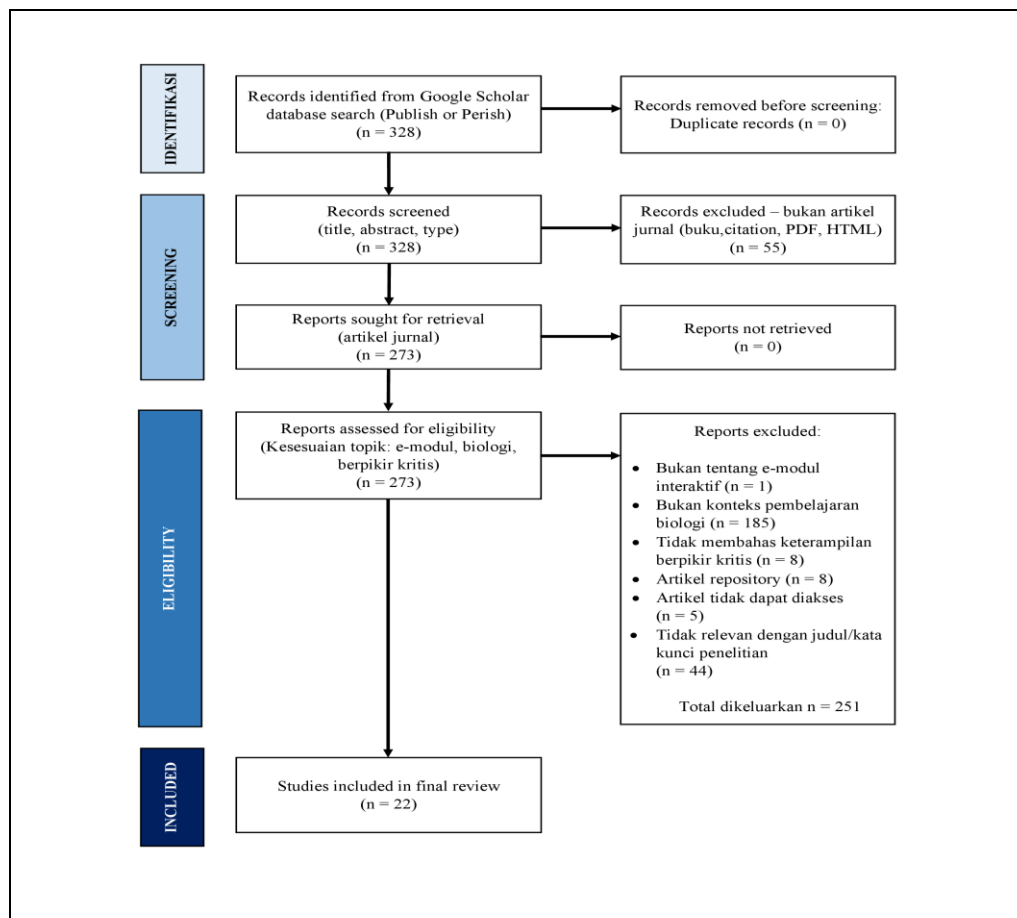


Figure 1. Flow diagram of article selection based on the PRISMA procedure

C. RESULTS AND DISCUSSION

Publication Trends Regarding the Use of Interactive E-Modules to Enhance Students' Critical Thinking Skills in Biology Instruction Over the Last Five Years

Publication Trends by Year

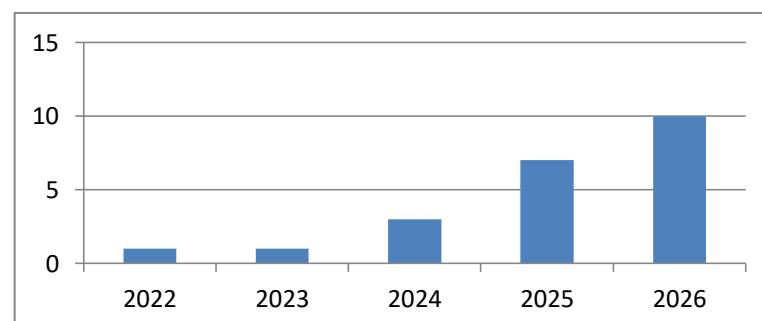


Figure 2. Distribution graph of publication years for E-Module Biology research (N=22)

Based on the distribution of publication years shown in Figure 2, research concerning the use and development of biology e-modules aimed at fostering students' critical thinking skills has experienced significant growth over the last five years (2022–2026). In total, 22 selected research articles reflect a shift in researchers' interests toward the utilization of interactive digital learning materials to support students' cognitive processes in biology education.

concerning the use of e-modules to enhance students' critical thinking skills in biology education into five thematic clusters.

Based on the visualization map shown in Figure 3, the keywords "e-module," "critical thinking skills," and "Problem-Based Learning (PBL)" emerge as the largest central nodes with the most frequent connections. This indicates that Problem-Based Learning (PBL) is the primary pedagogical framework most commonly associated with the development of interactive e-modules in the reviewed literature, as reported in various source studies (Mahajani et al., 2026; Afiya & Indrati, 2026; Semiati & Mawartiningsih, 2026; Azura et al., 2025). In addition to PBL, the clustering of topics also reveals a variety of other approaches, such as discovery learning (Rachmah & Raharjo, 2026; Pramudita & Rahayu, 2024), Project-Based Learning (PjBL) (Musdalifah & Trimulyono, 2026), *Socio Scientific Issues* (SSI) (Sugianto & Susantini, 2026), and the integration of Artificial Intelligence (AI) (Nurhasanah, 2026).

The next thematic cluster addresses aspects of product development. The presence of keywords such as "R&D," "4D model," "4D development model," "ADDIE model," and "media expert" indicates that the majority of studies utilize Research and Development (R&D) procedures specifically the Thiagarajan (4D) or ADDIE models which incorporate validation by media and subject-matter experts before the e-modules are implemented (Pramudita & Rahayu, 2024; Astuti et al., 2022). Regarding content scope, the analysis reveals that these e-modules cover a diverse range of biological topics, including the excretory system (Mahmud et al., 2025; Simbolon & Putra, 2026), the nervous system (Rachmah & Raharjo, 2026; Karmia et al., 2025), ecosystems and environmental pollution (Nabilla & Fawaida, 2026; Purba et al., 2026), as well as the study of viruses (Anggraini & Trimulyono, 2025).

Finally, the emergence of keywords such as "effectiveness," "N-gain score," "implementation," and "control class" indicates that the articles in the literature also evaluate products through experimental research. Although the VOSviewer bibliometric map does not directly measure learning outcomes, this thematic convergence suggests that the integration of R&D procedures, innovative learning models, and quantitative testing serves as a primary focus within the literature for transforming students' critical thinking skills in biology (Nirmala et al., 2025).

Learning Models or Approaches Used for the Development of Interactive E-Modules in Biology Instruction

The findings regarding the learning models or approaches identified in the 22 articles reviewed are presented in Table 1 below.

Table 1. Biological models or approaches in the development of e-modules

Category	Number of Articles	Authors & Year of Citation
Learning model		
<i>Problem Based Learning (PBL)</i>	9	Mahajani et al (2026); Nabilla & Fawaida (2026); Afiya & Indrati (2026); Semiati & Mawartiningsih (2026); Simbolon & Putra (2026); Purba et al (2026); Azura et al (2025); Anggraini & Trimulyono (2025); Sartika et al (2024)
<i>Discovery Learning</i>	2	Rachmah & Raharjo (2026); Pramudita & Rahayu (2024)
<i>Project Based Learning (PjBL)</i>	1	Musdalifah & Trimulyono (2026)
<i>Guided Inquiry</i>	1	Afifah et al (2024)
<i>Socio-Scientific Issues</i>	1	Sugianto & Susantini (2026)

(SSI)		
Learning Cycle 7E	1	Patekur, (2023)
	Learning Approach	
Scientific Approach	1	Tianah & Asri (2025)
Based on educational tourism	1	Sukmayanti et al., (2024)
Research-based study on the use of kabau fruit peels as an antibacterial agent	1	Sitorus et al., (2025)
	Device	
eXe Learning	1	Karmia et al., (2025)
Flip PDF Corporate Edition	1	Astuti et al., (2022)
Artificial Intelligence	1	Nurhasanah, (2026)
Total	21	21 Synthesized Articles

Data analysis of the 22 identified articles revealed that 21 specifically discuss the models, approaches, tools, or media employed. Among the selected articles, Problem-Based Learning (PBL) emerged as the most frequently used model in the development of biology e-modules, appearing in 9 articles. The preference for PBL is rooted in the suitability of its syntax such as problem orientation, organization of learning, and independent inquiry which conceptually encourages students to critically analyze biological issues (Mahajani et al., 2026; Purba et al., 2026). The application of the PBL model is largely focused on biology topics closely linked to everyday life phenomena or local environmental issues, including subjects such as environmental pollution, ecosystems, the digestive system, and fungi (Afiya & Indrati, 2026; Semiati & Mawartiningsih, 2026; Sartika et al., 2024).

In addition to the Problem-Based Learning (PBL) model, researchers have also utilized various other inquiry-oriented models. These include Discovery Learning (featured in 2 articles), as well as Guided Inquiry, Socio-Scientific Issues (SSI), the Scientific Approach, and the Learning Cycle each of which appears in 1 article. For instance, Discovery Learning has been employed to guide students in independently discovering concepts related to the structure and function of plant tissues and the nervous system (Rachmah & Raharjo, 2026; Pramudita & Rahayu, 2024). Furthermore, the Socio-Scientific Issues (SSI) model has been used to engage students in evaluating dilemmas at the intersection of science and society (Sugianto & Susantini, 2026), while Project-Based Learning (PjBL) has been applied through the design of innovative biotechnological products, a process that requires high-level reasoning (Musdalifah & Trimulyono, 2026).

In addition to the Problem-Based Learning (PBL) model, researchers have employed various other innovative instructional models, including Discovery Learning (featured in two articles), as well as Guided Inquiry, Socio-Scientific, and Learning Cycle models (each appearing in one article). Regarding content or contextual approaches, the literature highlights the use of local environmental contexts, environmental issues, and educational tourism for instance, an educational tourism approach focused on pteridophytes (ferns) to enhance students' critical thinking skills (Sukmayanti et al., 2024), as well as e-modules based on laboratory research concerning antibacterial properties (Sitorus et al., 2025). In this context, "local" is operationally defined as the utilization of the physical environment, surrounding natural phenomena, and local educational tourism sites, excluding traditional knowledge systems or ethnobiological approaches. Meanwhile, the platforms or software used to develop interactive media are categorized separately, encompassing the use of eXe-Learning software (Karmia et al., 2025) and AI-based digital platforms (Nurhasanah, 2026). This taxonomic distinction between pedagogical models, content approaches, and software demonstrates that

interactive biology e-modules are highly flexible and can be tailored to the specific characteristics of the subject matter and the targeted critical thinking indicators.

Platforms or Software and Forms of Interactivity Used in E-Modules

The results of the identification of articles concerning platforms or software, as well as the features and forms of interactivity found, can be seen in Table 2 below.

Table 2. Platforms/Software And Forms of Interactivity in E-Modules

Analysis Category	Platform/Software and Features	Interactivity	Related Articles
Interactive multimedia (video, animation, sound effects, simulations)	Canva, converted to flipbook format	Learning text, images, and videos	Sugianto & Susantini, (2026)
	eXe Learning	Text, images, videos, and interactive exercises	Karmia et al., (2025)
	PDF format or interactive web page	Interactive elements such as quizzes and videos	Mahmud et al., (2025)
	Heyzine Flipbook; Bio-Think, Bio-Analyze, Bio-Lab, Bio-Discussion, Bio-Reflection	Animations, images, videos, and QR codes	Pramudita & Rahayu, (2024)
	Microsoft Word, Canva, Flip PDF Corporate Edition	Photos or videos added to the e-module	Astuti et al., (2022)
	Heyzine Flipbook Maker	Sound effects for page-turning, images, text, and videos	Musdalifah & Trimulyono, (2026)
	Heyzine Flipbook; Bio-Orientation, Bio-Watch, Bio-Concept, Bio-Activity, Bio-Present, Let's Practice, Bio-Eval	Bio-Watch: educational videos on the topic of viruses	Anggraini & Trimulyono, (2025)
	Heyzine; Let's Observe, Let's Ask Questions, Let's Think, Let's Explore, Let's Discuss	Video materi dalam e-modul flipbook	Tianah & Asri, (2025)
	BioInfo, Bio-Media, Edu-Times, Edu-Lab	Interactive simulations from the PhET platform	Simbolon & Putra, (2026)
Supporting static visuals (images, illustrations, visual media)	Bio-Orientation, Bio-Eval	Authentic visual media as an initial stimulus for learning	Semiati & Mawartiningsih, (2026)
	Berbasis AI	Images, contextual problems, and the-spark questions (prompts to ignite inquiry)	Nurhasanah, (2026)
	Curipod (AI-based web) dan Canva	Covers, illustrations, and activity sheets	Mahajani et al., (2026)
	Canva (website)	Icons, illustrations, colors, and supporting images	Afiya & Indrati, (2026)
Navigation and interactive links (hyperlinks, QR codes, external links)	Heyzine Flipbook; Bio-Think	Website links, hyperlinks, QR codes, and external links	Pramudita & Rahayu, (2024)
	Flip PDF Corporate Edition	Hyperlinks integrated into each menu	Astuti et al., (2022)
	Heyzine flipbook	Evaluation questions, scoring rubrics,	Tianah & Asri, (2025)

		reflection journals, and answer keys provided via hyperlinks	
Interactive evaluations (quizzes, exercises, case studies, digital worksheets)	Bio-Orientation, Bio-Eval	Contextual problems in mycology and electronic assessment with critical thinking indicators	Semiati & Mawartiningsih, (2026)
	eXe Learning	Interactive exercises	Karmia et al., (2025)
	Format PDF atau halaman web interaktif	Quizzes	Mahmud et al., (2025)
	Bio-Discussion, Bio-Reflection	Questions on course material and laboratory work; self-assessment via Google Forms	Pramudita & Rahayu, (2024)
	Let's Practice, Bio-Eval	Practice questions to check understanding	Anggraini & Trimulyono, (2025)
	Flipbook interaktif	Case-based problems requiring high-level critical thinking	Sitorus et al., (2025)
	Heyzine flipbook	Assessment tasks, scoring rubrics, reflective journals, and answer keys	Tianah & Asri, (2025)
	Heyzine Flipbook; Bio-Case, Bio-Think, Bio-Activity, Bio-Summary, Bio-Evaluation	Case studies and assessments	Rachmah & Raharjo, 2(026)
	Canva (PDF) diunggah ke Liveworksheets	Digital worksheets	Azura et al., (2025)
AI-based feedback	AI-based	AI can provide learning assistance and feedback, allowing students to improve their understanding.	Nurhasanah, (2026)

Table 2 includes 16 of the 22 articles reviewed. Of these 16 articles, 12 specify particular platforms or software. The remaining four articles mention only general formats: PDF or interactive web pages (Mahmud et al., 2025), interactive flipbooks (Sitorus et al., 2025), AI-based media (Nurhasanah, 2026), and modules incorporating authentic visual media (Semiati & Mawartiningsih, 2026). Heyzine Flipbook is the most frequently cited, appearing in five articles (Anggraini & Trimulyono, 2025 ; Musdalifah & Trimulyono, 2026; Pramudita & Rahayu, 2024; Rachmah & Raharjo, 2026; Tianah & Asri, 2025). Canva is also featured in five articles (Afiya & Indrati, 2026; Astuti et al., 2022; Azura et al., 2025; Mahajani et al., 2026; Sugianto & Susantini, 2026). Other software tools appear in only one article each: eXe Learning (Karmia et al., 2025), Flip PDF Corporate Edition (Astuti et al., 2022), Curipod (Mahajani et al., 2026), PhET simulations (Simbolon & Putra, 2026), and Liveworksheets (Azura et al., 2025). This pattern indicates that the development of biology e-modules still relies primarily on flipbook-creation and graphic-design applications, while AI-based platforms appear in only a small fraction of the studies.

Interactive multimedia is the most frequently reported feature, with video being the predominant form, appearing in eight articles. These videos are embedded within e-modules presented as flipbooks, PDFs, or web pages. An example is a video on the topic of viruses found in the "Bio-Watch" section (Anggraini & Trimulyono, 2025). Other forms of multimedia are much less common. Animations and QR codes were reported by Pramudita & Rahayu, (2024), sound effects accompanying page-turning by Musdalifah and Trimulyono

(2026), and interactive simulations from PhET by (Simbolon & Putra, 2026). Thus, in this corpus, the term "interactive multimedia" largely refers to embedded videos rather than simulations that students can manipulate.

Interactive evaluation accounts for the same number of studies as multimedia nine articles. These take various forms: interactive exercises (Karmia et al., 2025), quizzes (Mahmud et al., 2025), case-based problems (Rachmah & Raharjo, 2026; Sitorus et al., 2025), electronic evaluations incorporating critical thinking indicators (Semiaty & Mawartiningsih, 2026), and digital worksheets on the Liveworksheets platform (Azura et al., 2025). Pramudita & Rahayu, (2024) utilized Google Forms for self-assessment, while Tianah & Asri, (2025) supplemented evaluation questions with scoring rubrics, reflective journals, and hyperlinked answer keys. Navigation features and interactive links were reported in only three articles (Astuti et al., 2022; Pramudita & Rahayu, 2024; Tianah & Asri, 2025). Four other articles included supporting static visuals such as illustrations, contextual problems, and the use of "trigger" questions which served as initial stimuli (Afiya & Indrati, 2026; Mahajani et al., 2026; Nurhasanah, 2026; (Semiaty & Mawartiningsih, 2026).

Claims regarding AI-based automated feedback should be restricted to the articles that explicitly report on it. In this instance, only Nurhasanah, (2026) discusses this feature, and even then, only as a potential capability specifically, the idea that AI could provide learning support and feedback to help students improve their understanding. The table does not indicate that this feature was actually implemented or tested with students. Other articles involving Curipod highlight different features; for example, Mahajani et al., (2026)note the use of Curipod and Canva to generate covers, illustrations, and activity sheets. Consequently, real-time, two-way interaction and automated feedback cannot yet be classified as empirical findings; rather, they are better described as technological potentials mentioned in a single study. With the exception of AI-based feedback, all other features are those explicitly reported by the source studies. Some statements in this review are inferential and should be distinguished from the actual data. The discussion should clarify that these features are designed to facilitate critical thinking, rather than asserting that they have been proven effective.

These findings carry two implications. First, while interactive and multimedia-based evaluation has become a common component, the interactivity remains dominated by relatively simple forms, such as embedded videos and self-administered exercises. Features requiring dynamic responses such as simulations (Simbolon & Putra, 2026)and adaptive feedback remain very limited. Second, the categories of features most relevant to critical thinking namely case-based tasks, contextual problems, and reflective journals are reported in only a small fraction of the articles. Future developers of e-modules could integrate established flipbook formats with evaluation features that explicitly incorporate indicators of critical thinking, as demonstrated by (Semiaty & Mawartiningsih, 2026)

Key Findings and Important Information Serving as a Reference for Developing Interactive Biology E-Modules to Enhance Critical Thinking Skills, Based on Reviewed Articles

The results of the identification of articles, regarding the key findings and information from each article reviewed, are presented in Table 3 below.

Table 3. Key Findings And Important Information

N o	Author (year)	Design	Sample	Instrument	Comparator (if any)	Main reported outcomes
1	Karmia et al., (2025)	Descriptive quantitative	XI SMA	Critical thinking	Control class with	The systematic structure of the eXe

		quasi-experiment; Nonequivalent Control Group Design		skills test	conventional instruction	Learning-based e-module is reported to support a logical reasoning flow for the material on the nervous system.
2	Purba et al., (2026)	Experiment; pretest-posttest control group design	X SMA	Critical thinking skills test and observation sheet	Control class using the direct instruction model	PBL e-modules featuring problems relevant to daily life have been reported to strengthen the ability to analyze ecosystem components.
3	(Nurhasanah, (2026)	Quasi-experiment; Nonequivalent Control Group Design	The school and grade level are not specified (it is a single school that conducts biology instruction).	Scientific literacy test and critical thinking skills test	Control class using conventional teaching materials	E-modules featuring AI-driven adaptive responses and feedback were reported to foster critical thinking skills among learners in the treatment group.
4	Afifah et al., (2024)	R&D Lee and Owens	X SMA	Interviews and questionnaires (needs analysis); tests and questionnaires (research); assessment questionnaires for subject matter experts, media experts, teaching material experts, field practitioners, and students	Having a control class	Guided inquiry-based e-modules with a systematic approach are reported to be effective in fostering students' critical thinking skills and digital literacy.
5	Sugianto & Susantini, (2026)	4D	11th-grade high school student	Observation sheet for the implementation of instruction; critical thinking tests (pre-test and post-test)	There isn't any	E-modul dengan model isu kontroversial pada materi biologi yang kompleks dilaporkan melatih kemampuan berpikir kritis dan argumentasi; peningkatan skor diperoleh dari pre-test dan post-test tanpa pembandingan.
6	Sartika et al., (2024)	R&D (ADDIE)	XI SMA	Validation sheets for	There isn't any	An interactive e-module featuring

				content and media experts; student response questionnaire; tests (pretest-posttest)		exercises that can be completed directly was associated with an increase in critical thinking scores between the pre-test and post-test; however, in the absence of a comparison group, this improvement cannot be definitively attributed to the e-module.
7	Mahmud et al., (2025)	R&D (ADDIE)	XI SMA	Essay tests in the pretest and posttest	There isn't any	The e-module, integrated with Canva, contains interactive exercises; critical thinking is measured through indicator-based essay tests administered as pre-tests and post-tests.
8	Nabilla & Fawaida, (2026)	Quantitative pre-experimental ; One-Group Pretest– Posttest	VIII MTs	Critical thinking skills test	There isn't any	An environmental issue-based e-module is used to train students in analyzing environmental pollution; improvements in critical thinking scores are measured within a single group, without a comparison group.
9	Anggraini & Trimulyono, 2025)	R&D (4D)	X SMA	Validity, practicality, and effectiveness (pre-test and post-test based on critical thinking indicators)	There isn't any	The cases in the e-module are linked to training on explanatory indicators; effectiveness is assessed through pre-tests and post-tests, without a comparison group.
10	(Simbolon & Putra, 2026)	R&D (4D)	XI SMA	Product feasibility validation sheet; student response questionnaire; pre-test and post-test for critical thinking	There isn't any	A simulation of kidney disorders within an e-module is associated with an increase in critical thinking scores between pre-tests and post-tests, in the absence of a comparison group.
11	Semiati & Mawartiningsih, (2026)	R&D (4D)	X SMA	Expert validation sheet; five-point Likert scale closed-ended questionnaire	There isn't any	The PBL e-module, featuring authentic visual media, has been deemed suitable by experts as a means to shift from the rote memorization of

				e		abstract concepts regarding fungi toward analytical activities.
12	Pramudita & Rahayu, (2024)	R&D (4D)	XI SMA	Media and content expert validation sheet	There isn't any	Interactive images in the e-module are considered suitable by experts for supporting concept discovery and analysis.
13	Astuti et al., (2022)	R&D (4D)	XII SMA	Validity sheet	There isn't any	The e-module was developed using Microsoft Word, Canva, and Flip PDF Corporate Edition, and it incorporates critical thinking indicators; its suitability was assessed through validation.
14	(Mahajani et al., (2026)	R&D (ADDIE)	XI SMA	Media expert and subject matter expert validation sheet	There isn't any	The integration of Curipod is considered capable of enhancing the interactivity of e-modules, which supports the implementation of the *Kurikulum Merdeka* (Independent Curriculum); Problem-Based Learning (PBL) is used as an approach for presenting material on the excretory system.
15	Afiya & Indrati, (2026)	R&D (ADDIE)	VII SMP	Validation sheet	There isn't any	The e-module leverages potential local issues as a context for practicing critical thinking indicators; its suitability is assessed through validation.
16	Musdalifah & Trimulyono, (2026)	R&D (4D)	X SMA	Validation sheet and practicality validation	There isn't any	The PjBL e-module guides students in designing biotechnology products to develop skills in analysis, evaluation, and explanation; it has been assessed as both valid and practical.
17	Sitorus et al., (2025)	R&D	Mahasiswa	E-module validation sheet	There isn't any	Biology teaching materials based on local research into the antibacterial properties of "kabau" have been deemed suitable through validation; however, their impact on critical thinking skills has not yet been

						tested.
18	Tianah & Asri, (2025)	R&D (4D)	X SMA	Validation sheet of feasibility and effectiveness	There isn't any	The learning stages in the e-module (observing, questioning, reasoning, and communicating) are designed to foster a systematic, critical mindset; they are evaluated through expert validation.
19	Rachmah & Raharjo, (2026)	R&D (4D)	XI SMA	Validation by three validators; implementation of the discovery learning syntax by two observers; student response questionnaire	There isn't any	The visualization of sensory organs in the discovery learning-based e-module is linked to indicators of inference, interpretation, analysis, and explanation; the e-module is considered valid and practical, though data regarding changes in critical thinking are not reported.
20	Azura et al., (2025)	R&D (4D)	IX SMA	Validation by subject matter and media experts; teacher and student response questionnaires	There isn't any	The Liveworksheets-based e-module is considered valid and practical, and it is designed to identify students' critical thinking skills.
21	Patekur, (2023)	Quantitative descriptive and ADDIE	XII MIPA	Google Form-based needs analysis questionnaire for students and teachers	There isn't any	The 7E cycle in the e-module is designed to present abstract genetic material in a way that makes it easier to analyze.
22	Sukmayanti et al., (2024)	R&D (4D)	X SMA	Validation sheet and questionnaire for teacher and student responses	Not specified	An e-module featuring educational tourism-themed visuals is designed to facilitate critical observation and classification.

The mapping results indicate that the reviewed articles are not equivalent in terms of the strength of evidence; therefore, the contribution of each group is interpreted within the limitations of its respective research design. Four articles (Karmia et al., 2025; Purba et al., 2026; Nurhasanah, 2026; Afifah et al., 2024) examine the impact of e-modules on critical thinking by employing a comparison group specifically, classes that utilized conventional instruction, direct instruction, or traditional teaching materials. Given their use of quasi-experimental or experimental designs, the strength of evidence in these four articles is

considered moderate. However, Table 3 does not yet include statistical values or effect sizes, making it impossible to compare the magnitude of the impact across these studies.

Six articles (Sugianto & Susantini, 2026; Sartika et al., 2024; Mahmud et al., 2025; Nabilla & Fawaida, 2026; Anggraini & Trimulyono, 2025; Simbolon & Putra, 2026) utilize pre-tests and post-tests to assess critical thinking without a comparison group. Changes in scores within these groups could be influenced by factors other than the e-modules such as prior experience with the same test or other learning activities occurring during the intervention resulting in a strength of evidence rated as low to moderate. Ten articles (Semiati & Mawartiningsih, 2026; Pramudita & Rahayu, 2024; Astuti et al., 2022; Mahajani et al., 2026; Afiya & Indrati, 2026; Musdalifah & Trimulyono, 2026; Sitorus et al., 2025; Tianah & Asri, 2025; Rachmah & Raharjo, 2026; Azura et al., 2025) report only on the validity or practicality of the products. Developmental studies of this nature indicate that an e-module is suitable for use, yet this is insufficient to conclude that it enhances critical thinking skills. Two other articles (Patekur, 2023; Sukmayanti et al., 2024) consist of needs analyses or contain ambiguous data regarding critical thinking; therefore, they are not used as evidence of effectiveness. Consequently, the claims made in this paper concerning the impact of e-modules on critical thinking are based solely on four articles. Six articles are treated as preliminary indicators, while the remainder serve as sources of ideas for feature design.

Features associated with analysis and inference indicators primarily appear in content that is abstract or involves complex processes. A systematic presentation structure has been shown to support logical reasoning in the study of the nervous system (Karmia et al., 2025), while the use of contextual problems has been found to strengthen the ability to analyze ecosystem components (Purba et al., 2026). Both of these articles are comparative studies. The use of simulations of kidney disorders within the study of the excretory system (Simbolon & Putra, 2026) was associated with an increase in critical thinking scores, though this study lacked a comparison group. Meanwhile, visualizations of sensory organs (Rachmah & Raharjo, 2026) and interactive images for the study of plant tissues (Pramudita & Rahayu, 2024) were deemed appropriate by experts, but no data regarding changes in critical thinking were provided.

Regarding the indicators of evaluation and explanation, the only comparative evidence relates to an artificial intelligence (AI)-based adaptive response system that incorporates feedback (Nurhasanah, 2026). As only one article has examined this feature, the claim that AI-based real-time feedback enhances critical thinking cannot yet be generalized. Other features are supported by weaker evidence, including the use of controversial issues within complex biological subject matter (Sugianto & Susantini, 2026), case-based exercises for developing explanations (Anggraini & Trimulyono, 2025), problems concerning environmental pollution (Nabilla & Fawaida, 2026), and interactive, fillable tasks embedded within e-modules (Sartika et al., 2024).

Local environmental issues and controversial topics can provide a socio-cultural context for learning; however, they do not, in themselves, constitute ethnobiology. Two articles addressing local issues or research (Afiya & Indrati, 2026; Sitorus et al., 2025) focus on validity studies and do not report on local community knowledge, cultural practices, or human relationships with living organisms as material for student analysis. Other articles addressing environmental concerns (Purba et al., 2026; Nabilla & Fawaida, 2026) emphasize the analysis of ecological problems. Consequently, evidence regarding ethnobiology-based biology e-modules designed to foster critical thinking is currently absent from this corpus; this is identified as a gap in the evidence rather than a research finding. Based on the synthesis above, a framework for an ethnobiology-based biology e-module aimed at developing critical thinking has been developed, consisting of three components: (1) content based on contextual problems, (2) an active learning syntax, and (3) two-way interaction accompanied by

feedback. This framework serves as a hypothetical conceptual proposal rather than a validated model.

Contextual issues are addressed in some of the articles; active learning syntax appears in eight articles, while two-way interaction or feedback is featured in five. Each component is represented in at least one study: Purba et al., (2026) cover components 1 and 2; Afifah et al., (2024) component 2; and Nurhasanah (2026) focuses on component 3. Nevertheless, no single article examines all three components simultaneously. Certain articles could not be categorized under these three components because their primary features consist of specific visual interfaces or software (Astuti et al., 2022; Sukmayanti et al., 2024; Pramudita & Rahayu, 2024), while Karmia et al., (2025) focus solely on the structure of the presentation.

Given these limitations, the proposed e-module should not be viewed merely as a digital conversion of a textbook, but rather as a tool that integrates all three components. The effectiveness of combining these three components warrants further investigation for instance, by applying them to the subject of plants and incorporating local indigenous knowledge, an aspect currently unrepresented in the existing corpus.

D. CONCLUSION

1. Among the 22 selected articles, publications concerning interactive e-modules designed to foster critical thinking skills in biology education show an upward trend: from 1 article each in 2022 and 2023 (4.5% per year), to 3 articles in 2024 (13.6%), 7 in 2025 (31.8%), and 10 in 2026 (45.5%). The peak in publications occurred during the 2025–2026 period, with the figure for 2026 potentially increasing further as the year has not yet concluded. This pattern reflects a growing research interest in the topic, which the reviewed literature links to curriculum policy directions and the digitalization of education both of which emphasize student-centered learning. This connection is an implication drawn from the referenced literature rather than a finding measured directly from the distribution of publication years. These conclusions are limited to the articles that met the selection criteria; furthermore, the coverage of biology topics remains uneven dominated by the excretory system, nervous system, ecosystems, and viruses and the representation of local contexts is still limited. Consequently, these results cannot be generalized to all biology topics or every learning context. Future research is encouraged to broaden the scope of subject matter and investigate e-modules that incorporate local contexts.
2. The most dominant and widely used learning model in the development of interactive e-modules is Problem-Based Learning (PBL), as its syntax supports the critical analysis of biological issues.
3. Overall, the development trend for biology e-modules remains centered on the use of flipbook-creation applications and general graphic design platforms. Although some research has incorporated authentic visual media, web-based formats, simulations, and interactive worksheets, the integration of AI-driven platforms and specialized interactive software remains relatively low, appearing only to a limited extent.
4. The strength of evidence varies across the articles. Only four articles examined the impact of e-modules on critical thinking using a comparison group. Six articles employed pre-tests and post-tests without a comparison group, while ten articles reported only on the validity or practicality of the products. Within this context, interactive e-modules show potential for supporting critical thinking indicators—such as analysis, inference, and evaluation particularly when addressing abstract and complex topics like the excretory system, the nervous system, and ecosystems. However, this potential cannot yet be concluded as proven effectiveness, as statistical values and effect sizes are not comparable across studies, research designs vary, and the instruments used are diverse. Consequently, the development of e-modules should ideally integrate contextual problems, active

learning frameworks, and two-way interaction with feedback a conceptual proposal that still requires further empirical testing.

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