Development of an AI-Based E-Module for Adaptive Learning to Enhance Students Critical Thinking

Achmad Ramadhan; Sutrisnawati; Liles Tangge; I. Nengah Kundera; I. Made Budiarsa
Department of Biology Education, Faculty of Teacher Training and Education, Universitas Tadulako, Jl. Soekarno Hatta Km. 9, Tondo, Palu 94148, Central Sulawesi, Indonesia

Corresponding Author: **Achmad Ramadhan**

Abstract: The rapid advancement of digital learning demands innovative approaches to support students' higher-order thinking skills. This study aimed to develop and evaluate an AI-based adaptive e-module designed to enhance critical thinking in the Animal Development course. Employing a Research and Development (R&D) approach with the ADDIE model, the study involved 25 biology education students. The module integrated multimedia content, adaptive quizzes, and a chatbot powered by natural language processing to provide personalized learning paths. Expert validation confirmed high feasibility (86%, very feasible) in terms of pedagogy, content, and technology. Implementation results revealed a significant improvement in students' performance, with average scores increasing from 52.0 (pre-test) to 80.6 (post-test). Statistical analysis showed a significant effect ($t(24) = 14.21$, $p < 0.0001$), and the N-gain score of 0.60 indicated a moderate to high improvement. Student surveys further reported high satisfaction, with over 90% positive responses regarding usability, interactivity, and relevance. Qualitative feedback emphasized that the chatbot and adaptive quizzes stimulated reflective and critical learning. These findings demonstrate that AI-based adaptive e-modules can effectively address learning gaps and foster critical thinking in complex biological topics. The study contributes a practical model for integrating adaptive learning and AI into higher education.

Keywords: Adaptive Learning; E-Module; Artificial Intelligence; Critical Thinking; Biology Education

Introduction

The use of e-modules integrated with adaptive learning technology has emerged as a modern approach to improving the quality of education. Adaptive learning platforms are designed to tailor educational content in real time to individual students' needs and abilities[1,2]. When combined with e-modules, adaptive learning enables more personalized and interactive learning experiences, thereby supporting students' conceptual understanding in complex subjects such as biology[3]. The integration of artificial intelligence (AI) in adaptive learning has further enhanced its effectiveness by providing real-time feedback and adjusting learning paths according to students' progress[4,5,6,7]. Previous studies have also confirmed that AI-powered adaptive learning systems increase students' engagement and academic performance through personalized pathways[8].

Despite these promising results, challenges remain in developing higher-order thinking skills, particularly critical thinking, which is considered a key competence for 21st-century learners[9,10]. Several studies have indicated that many university students still struggle to develop critical thinking skills due to the limitations of conventional teaching methods. For instance, classroom observations at the Biology Education Study Program, Faculty of Teacher Training and Education, Tadulako University revealed that more than 60% of students in the Animal Development course had difficulties understanding abstract concepts such as cell differentiation, organogenesis, and regulatory mechanisms of development. Their average score in critical thinking tests was only 45%, which is below the minimum passing standard. These findings highlight the need for innovative teaching approaches that not only provide access to learning materials but also foster critical thinking through adaptive feedback mechanisms.

To address this issue, this study proposes the development of an AI-based e-module that integrates adaptive learning features such as natural language processing (NLP)-driven chatbots and adaptive quizzes[11,12,13] The chatbot allows two-way interactions between students and the system, offering reflective feedback and stimulating analytical discussions[14,15]. Meanwhile, adaptive quizzes dynamically adjust question difficulty based on students' real-time performance. This combination of features is expected to create a more personalized, dynamic, and engaging learning environment that promotes conceptual understanding and critical thinking[16,17,18].

Although adaptive learning has been successfully implemented in mathematics and science education[19,20] research specifically focusing on the effectiveness of AI-based adaptive e-modules in the context of biology—particularly in complex subjects such as animal development—remains limited. Therefore, this study aims to fill this research gap by developing and evaluating an AI-based adaptive e-module designed to enhance critical thinking skills among biology students. The findings of this study are expected to contribute both theoretically and practically by (1) providing a novel instructional model

for biology education and (2) serving as a reference for future research and development of AI-based digital learning systems.

Methods

Research Design

This study employed a Research and Development (R&D) approach using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) to develop an AI-based adaptive e-module for the Animal Development course. The ADDIE model was selected due to its systematic yet flexible framework in guiding the development of technology-enhanced instructional media.

Participants

The participants consisted of 25 undergraduate students enrolled in the Animal Development course at the Biology Education Study Program, Faculty of Teacher Training and Education, Tadulako University. A purposive sampling technique was applied, focusing on students who had completed prerequisite biology courses. In addition, three subject-matter experts (two biology lecturers and one instructional media specialist) were involved in the validation process.

Procedure

The research followed the five stages of the ADDIE model[21]:

Analysis

- Needs analysis: Surveys and interviews with students and lecturers were conducted to identify learning challenges and expectations regarding adaptive learning.
- Literature review: Previous studies on adaptive learning in higher education, particularly in biology, were analyzed.
- Curriculum analysis: Learning outcomes and competencies of the Animal Development course were examined to ensure alignment with the e-module design.

Design

Development of multimedia-based content (interactive videos, case studies on embryonic development).Specification of adaptive features, including rules for adjusting quiz difficulty and feedback mechanisms.Initial prototyping in a Learning Management System (LMS) environment (Moodle).

Development

Construction of the AI-based adaptive e-module integrating NLP chatbot and adaptive quizzes.Expert validation in terms of pedagogy, content accuracy, and

technological feasibility.Small-scale pilot testing (beta test) with a limited group of students to gather feedback on usability and effectiveness.

Implementation

Full deployment of the e-module in the Animal Development course.Pre-test and post-test were administered to measure students' critical thinking skills before and after using the e-module.Observations and semi-structured interviews were conducted to assess student engagement and identify technical challenges.

Evaluation

Quantitative analysis of pre-test and post-test scores using paired-sample t-test and normalized gain (N-gain) to determine improvement in critical thinking.Qualitative analysis of student and lecturer feedback to evaluate user satisfaction.Revision of the e-module based on evaluation results for further dissemination.

Instruments

Critical Thinking Test: Adapted from standardized instruments, validated by three experts in biology education. Reliability was measured using Cronbach's Alpha (α = 0.82).Questionnaire: Administered to assess students' perceptions and satisfaction with the e-module.Interview Guide: Semi-structured interviews to collect qualitative feedback.Observation Sheet: Used to monitor student engagement during implementation.

Results

Needs Analysis

The pre-test results served as the foundation for the needs analysis. Of the 25 participating students, 17 (68%) scored below 60, with an overall mean score of 52.00 (SD = 8.47). This indicates that the majority of students had insufficient critical thinking skills at the outset, particularly in analyzing and evaluating complex biological concepts such as cell differentiation and organogenesis. These findings confirmed the need for an innovative learning resource capable of providing adaptive feedback and supporting students' development of higher-order thinking skills.

Design and Development of the E-Module

Based on the needs analysis, the AI-based adaptive e-module was designed systematically using the ADDIE model. The development process aligned the content with the learning objectives of the Animal Development course, particularly focusing on complex topics where students had previously shown difficulties. The module consisted of

four main units, each integrating interactive learning materials, adaptive assessments, and a Natural Language Processing (NLP)-based chatbot to foster critical thinking.

Each unit was designed with specific learning objectives, multimedia resources, and adaptive features to personalize the learning process (table 1). For instance, in Unit 2 on cell differentiation, a chatbot was integrated to encourage reflective responses such as, "Why is cell differentiation essential for multicellular organisms?". Similarly, in Unit 3 on organogenesis, the adaptive quiz adjusted its difficulty based on student performance, while the chatbot provided hints or probing questions to promote deeper reasoning.

Overall, the design and development stage ensured that the module did not merely deliver content but actively guided students through personalized learning paths. By embedding adaptive quizzes and reflective chatbot interactions, the e-module encouraged learners to analyze, evaluate, and synthesize biological concepts. This combination of multimedia learning materials and AI-driven adaptivity was intended to strengthen students' engagement while addressing their diverse learning needs.

Table 1: Outline of the AI-Based Adaptive E-Module for Animal Development

Unit	Learning Topic	Learning Objectives	Main Content / Materials	Adaptive Features
1	Introduction to Animal Development	Students explain the fundamental processes of gametogenesis and fertilization.	Text-based explanations; interactive diagrams of gamete formation; video introduction to fertilization mechanisms.	Adaptive quiz: If score <60, system provides simpler recall questions; ≥60, system offers applied analysis questions.
2	Cell Differentiation	Students analyze mechanisms of cell specialization and relate them to tissue formation.	Case study on stem cell differentiation; animations showing specialization steps; short readings with discussion prompts.	Chatbot prompts reflective questions (e.g., "Why is cell differentiation essential for multicellular organisms?").
3	Organogenesis	Students evaluate the sequential stages of organ development and identify critical	Video lecture on organogenesis; infographic timeline of organ formation; problem-solving	Adaptive quiz: Difficulty increases with correct answers; chatbot offers hints or probing questions

Unit	Learning Topic	Learning Objectives	Main Content / Materials	Adaptive Features
		regulatory factors.	worksheet on organ development disorders.	for incorrect ones.
4	Regulation of Development	Students critically assess genetic and hormonal regulation in embryonic development.	Research article summaries; interactive simulation of gene regulation; guided discussion questions on experimental findings.	Chatbot generates higher-order probing questions; personalized feedback directs students to supplementary materials.

Expert Validation and Feasibility

The developed e-module underwent validation by three experts: one in biology education, one in pedagogy, and one in educational technology. The validation focused on four aspects: content accuracy, pedagogical design, technical feasibility, and media usability. Each aspect was assessed using a 5-point Likert scale (1 = very poor, 5 = excellent).

The results, summarized in Table 2, indicate that all aspects of the module were rated highly feasible. The average overall validation score was 4.3 out of 5 (86%), which falls into the category of "very feasible." Content accuracy and pedagogical design obtained the highest mean ratings, showing strong alignment with the course learning outcomes and effective integration of adaptive learning strategies. Meanwhile, technical feasibility and usability also scored above 80%, though experts recommended minor revisions to enhance interface clarity and navigation flow.

Table 2: Expert Validation Results of the Adaptive E-Module

Validation Aspect	Mean Score (out of 5)	Percentage (%)	Category
Content Accuracy	4.5	90	Very feasible
Pedagogical Design	4.4	88	Very feasible
Technical Feasibility	4.2	84	Feasible
Media Usability	4.1	82	Feasible
Overall Average	**4.3**	**86**	**Very feasible**

Implementation Results: Pre-test and Post-test

The effectiveness of the AI-based adaptive e-module in improving students' critical thinking skills was assessed through pre-test and post-test scores. Table 3 presents the descriptive statistics and the results of the paired sample t-test.

Table 3. Results of Pre-test and Post-test Critical Thinking Scores (N = 25)

Statistic	Pre-test	Post-test
Mean	52.00	80.60
Standard Deviation	8.47	6.46
t-value (df = 24)	−17.3	
p-value	< 0.0001	
N-gain (average)	0.60	(moderate–high)

The results demonstrated a substantial improvement in students' critical thinking performance after the implementation of the adaptive e-module. The mean score increased from 52.00 (SD = 8.47) in the pre-test to 80.60 (SD = 6.46) in the post-test. A paired-sample t-test revealed a statistically significant difference ($t = -17.3$, $p < 0.0001$). Furthermore, the average normalized gain (N-gain) was 0.60, which falls within the moderate-to-high category, indicating that the intervention was effective in improving higher-order thinking. These findings align with the initial needs analysis, where 68% of students scored below the minimum standard of 60. After the intervention, nearly all students achieved scores above this threshold, demonstrating the capacity of AI-based adaptive learning to close learning gaps and foster critical thinking in complex biological contexts.

Student Engagement and Learning Experience

In addition to test performance, the adaptive e-module was evaluated in terms of student engagement and learning experience. Classroom observations indicated that more than 80% of students actively interacted with the NLP-based chatbot during learning sessions, while over 90% completed adaptive quizzes independently. These findings suggest that the module successfully encouraged active participation and fostered autonomous learning.

Survey data confirmed these observations, with students expressing strong positive perceptions of the module (Table 4).

Table 4. Student Perceptions of the Adaptive E-Module (N = 25)

Indicator	Positive Responses (%)	Category
Ease of use	88	Very Good
Interactivity	92	Very Good
Relevance to learning needs	84	Very Good
Contribution to critical thinking	86	Very Good
Overall satisfaction	90	Very Good

Qualitative feedback also provided valuable insights. Students reported that the adaptive quizzes motivated them to continuously improve their performance, while the chatbot promoted reflective learning. As one student explained, "The adaptive quizzes made me realize what I had not yet mastered, so I kept reviewing until I got better." Another remarked, "The chatbot's questions helped me think about the reasons behind biological processes instead of just memorizing them."

Overall, the findings demonstrate that the adaptive features of the e-module were well-received and contributed to creating a more interactive, personalized, and engaging learning environment.

Discussion

The findings of this study provide empirical support for the effectiveness of AI-based adaptive e-modules in improving students' critical thinking skills in biology education, particularly in the context of animal development. Several key aspects can be discussed in light of previous research.

First, the needs analysis revealed that 68% of students scored below the minimum threshold in the pre-test, underscoring the challenges faced by students in mastering complex biological concepts such as cell differentiation and organogenesis. This is consistent with previous reports highlighting the difficulties of higher-order cognitive processing in biology learning when traditional instructional methods are used [22][23]. The baseline data thus justified the development of an innovative intervention that not only delivered content but also scaffolded students' reasoning processes.

Second, the design and development of the adaptive e-module incorporated both multimedia resources and AI-driven adaptive features. This aligns with prior studies that emphasize the value of personalization and adaptivity in digital learning[24][25]. The integration of a chatbot using natural language processing was a distinctive feature of this study, as it enabled reflective dialogue and provided opportunities for critical questioning. Such interactive elements are rarely emphasized in existing adaptive modules, marking a novel contribution of this research[26][27].

Third, the expert validation process confirmed the feasibility and quality of the developed module, with an overall rating of 86% categorized as "very feasible." Expert feedback particularly valued the adaptive quizzes and chatbot prompts, while suggesting refinements to user interface and navigation. These results are in line with prior R&D studies in educational technology, which stress that iterative design and expert input are crucial for ensuring both pedagogical soundness and technical usability[28][29]

Fourth, the implementation results demonstrated a significant improvement in students' critical thinking skills. The average score increased from 52.0 to 80.6, with a large effect size confirmed by the paired-sample t-test ($p < 0.0001$) and an average N-gain of 0.60, categorized as moderate to high. This finding corroborates studies showing that adaptive learning systems can effectively enhance learning outcomes by tailoring content and feedback to individual learners [5][8]. The improvement observed in this study was particularly noteworthy, as nearly all students surpassed the minimum threshold after the intervention, suggesting that adaptive e-modules can help close achievement gaps in complex scientific domains.

Finally, evaluations of student engagement and learning experiences further strengthened the module's effectiveness. Over 90% of students reported positive perceptions of usability, interactivity, and relevance, while interviews highlighted that the chatbot encouraged reflection and deeper conceptual understanding. These results are consistent with previous evidence from meta-analyses and systematic studies that educational chatbots can improve student satisfaction, learning interest, and learning experiences, although results on motivation and engagement sometimes vary across contexts[30][31]. The chatbot also encouraged reflection and deeper conceptual understanding through adaptive feedback and personalized interactions[32][33].

Overall, the findings indicate that the AI-based adaptive e-module is not only technically and pedagogically feasible but also effective in supporting both cognitive and affective dimensions of learning. This study contributes to the growing body of literature on adaptive learning by integrating chatbot-mediated reflection with adaptive assessmenta combination that remains largely unexplored in the context of biology education.Recent research supports that AI-based adaptive e-modulesparticularly those integrating chatbot-mediated reflection and adaptive assessmentare technically and pedagogically effective, while also yielding positive impacts on both the cognitive and affective dimensions of learning. At the same time, they enrich the growing literature on innovation in biology education[34].

Conclusion

This study demonstrated that the development and implementation of an AI-based adaptive e-module in the Animal Development course significantly improved students' critical thinking skills. The pre-test analysis highlighted substantial learning gaps, while

the post-test results confirmed a marked improvement in performance with an N-gain score of 0.60, categorized as moderate to high. Expert validation indicated that the module was pedagogically and technologically feasible, and student surveys showed strong positive perceptions of its usability, interactivity, and contribution to deeper understanding. The integration of adaptive quizzes and chatbot-mediated reflection provided a personalized and engaging learning experience, supporting both academic achievement and critical thinking development. Overall, the findings affirm that adaptive learning technologies, when designed with AI features, can address the limitations of traditional teaching methods in complex biology courses.

References

1. Abdelrazek M, Badawy MG, Hamed A. AI-based adaptive personalized content presentation and exercises navigation for an effective and engaging E-learning platform. Published online 2023:3303-3333.
2. Contrino MF, Millán MR, Villegas PV, Hernández JM. Using an adaptive learning tool to improve student performance and satisfaction in online and face - to - face education for a more personalized approach. Published online 2024.
3. Honke N, Becker-genschow S. Adaptive learning in bionics : transforming science education. Front Educ. 2025;(February):1-21.
4. Gligorea, I.; Cioca M., Oancea, R.; Gorski, A.-T.; Gorski H., Tudorache P. Adaptive Learning Using Artificial Intelligence in e-Learning : A Literature Review. Educ Sci. 2023;13:1-27.
5. Fitri WA, Dilia MHH. Optimalisasi Teknologi AI Dalam Meningkatkan Efektivitas Pembelajaran. Sindoro Cendekia Pendidik. 2024;5(10).
6. Naseer F, Nasir M, Tahir M, Addas A, Aejaz SMH. Integrating deep learning techniques for personalized learning pathways in higher education. Heliyon. 2024;10(May).
7. Villegas-Ch W, Buenano-Fernandez D, Navarro AM, Mera-Navarrete A. Adaptive intelligent tutoring systems for STEM education: analysis of the learning impact and effectiveness of personalized feedback. Smart Learn Environ. 2025;12(1):41.
8. Casteleijn D, Franzsen D. Personalized adaptive learning in higher education : A scoping review of key characteristics and impact on academic performance and engagement. Heliyon. 2024;10(21):e39630.
9. Hutson, J., Jeevanjee, T., Graaf, V. V., Lively, J., Weber J, Weir, G., Arnone, K., Carnes, G. V, K., Plate, D., Leary, M., & Edele S. Artificial Intelligence and the Disruption of Higher Education : Strategies for Integrations across Disciplines. Creat Educ. 2022;13:3953-3980.
10. Gafarurrozi M, Rohman MF, Fathurrohman R. The Role of Artificial Intelligence as a Transformation of Learning in the Modern Era. 2024;8(1):32-39.

11. Ramteja Sajja,; Yusuf Sermet,; Muhammed Cikmaz,; David Cwiertny ID. Artificial Intelligence-Enabled Intelligent Assistant for Personalized and Adaptive Learning in Higher Education. arXiv. Published online 2023.
12. Chen DL, Aaltonen K, Lampela H, Kujala J. The Design and Implementation of an Educational Chatbot with Personalized Adaptive Learning Features for Project Management Training. Technol Knowl Learn. 2025;30(2):1047-1072.
13. Kaiss W, Mansouri K, Poirier F. Effectiveness of an Adaptive Learning Chatbot on Students' Learning Outcomes Based on Learning Styles. Int J Emerg Technol Learn. 2023;18(13 SE-Papers):250-261.
14. Chang DH, Lin MP chuan, Hajian S, Wang QQ. Educational Design Principles of Using AI Chatbot That Supports Self-Regulated Learning in Education : Goal Setting , Feedback , and Personalization. Sustainability. 2023;15:1-15.
15. Engeness I, Nohr M, Fossland T. Investigating AI Chatbots' Role in Online Learning and Digital Agency Development. Educ Sci. 2025;15(6).
16. Kumaresan V, Jeyakarthic M, Manjula Devi P, Jona Innisai Rani P, Mohan E, Surendra K. Personalized AI-Driven Online Education Technologies for Adaptive Learning and Cognitive Skill Enhancement. In: 2025 7th International Conference on Signal Processing, Computing and Control (ISPCC). ; 2025:1045-1050.
17. Hasanah H Al, Iswanto BH, Sugihartono I. AI-CBL : A Technology-Enhanced Learning Model Combining Chatbot and Case-Based Pedagogy to Improve Critical Thinking in Physics Education. JPPPF (Jurnal Penelit dan Pengemb Pendidik Fis. 2025;11(1):109-122.
18. Chen Y, Jensen S, Albert LJ, Gupta S, Lee T. Artificial Intelligence (AI) Student Assistants in the Classroom: Designing Chatbots to Support Student Success. Inf Syst Front. 2023;25(1):161-182.
19. Verma A, Kulkarnin R. Adaptive Learning Algorithms for Differentiated Instruction in Mathematics Education. Int Acad J Sci Eng. 2025;12(1 SE-Articles):50-53.
20. Zulpykhar Z, Kariyeva K, Sadvakassova A, Zhilmagambetova R, Nariman S. Assessing the Effectiveness of Personalized Adaptive Learning in Teaching Mathematics at the College Level. Int J Eng Pedagog. 2025;15(4 SE-Papers):4-22.
21. Mdodana-Zide L. Using ADDIE model for scaffolded learning and teaching intervention. Interdiscip J Educ Res. 2024;6(SE-Education Research Articles):1-15.
22. Luthfyanti J, Lutfi A, Sari IJ, et al. High School Students' Interests, Difficulties, and Conceptual Understanding of Cell Concepts. Biodidaktika J Biol dan Pembelajarannya. 2024;19(1):29-36.
23. Silaban OR. Exploring Common Misconceptions on the Cell Concept. Eurasia Proc Educ Soc Sci. 2024;39:46-54.
24. Siemens G. Learning Analytics: The Emergence of a Discipline. Am Behav Sci. 2013;57(10):1380-1400.

25. Kaouni M, Lakrami F, Labouidya O. The Design of An Adaptive E-learning Model Based on Artificial Intelligence for Enhancing Online Teaching. iJET. 2023;18(6):202-219.
26. Peng H, Ma S, Spector JM. Personalized adaptive learning : an emerging pedagogical approach enabled by a smart learning environment. Smart Learn Environ. 2019;6(9):1-14.
27. Paola G, Castro B, Chiappe A, Fernando D, Rodríguez B, Sepulveda FG. Harnessing AI for Education 4 . 0 : Drivers of Personalized Learning. Electron J e-Learning. 2024;22(5):1-14.
28. Liew A, Jie X, Kamrozzaman NA. The Challenges of Higher Education Students Face in Using Artificial Intelligence (AI) against Their Learning Experiences. Published online 2024:362-387.
29. Herlandy PB, Syahfutra W. An iterative design of ubiquitous learning modules for enhancing digital pedagogy in the Sekolah Penggerak . Res Dev Educ. 2025;5(1 SE-Articles):449-462.
30. Deng X. A Meta-Analysis and Systematic Review of the Effect of Chatbot Technology Use in Sustainable Education. Published online 2023.
31. Amin M, Nazik K, Salwa A. Interacting with educational chatbots : A systematic review. Educ Inf Technol. 2023;28:973-1018.
32. Liang H, Hwang G, Hsu T, Yeh J. Effect of an AI-based chatbot on students' learning performance in alternate reality game-based museum learning. Br J Educ Technol. 2024;55(5):2315-2338.
33. Tsz D, Ng K, Wei C, Jac T, Lok K. Empowering student self- - regulated learning and science education through ChatGPT : A pioneering pilot study. 2024;(August 2023):1328-1353.
34. Zhang R, Zou D, Cheng G. A review of chatbot-assisted learning: pedagogical approaches, implementations, factors leading to effectiveness, theories, and future directions. Interact Learn Environ. 2024;32(8):4529-4557