

Development of a Problem-Based Learning-Based E-Module to Enhance Critical Thinking Skills and Biology Concept Understanding Among Eleventh-Grade Senior High School Students

Rahmani, Fitri Arsih*, Muhyiatul Fadilah, Irdawati

Department of Master Biology Education, Universitas Negeri Padang, Padang, Indonesia

E-mail Corresponding: fitribio@fmipa.unp.ac.id

Received: May 31, 2026

Revised: July 25, 2026

Accepted: September 19, 2026

Abstract

This study was motivated by the limited use of digital teaching materials designed to strengthen students' critical thinking and biological concept understanding in the human circulatory system. Learning dominated by printed textbooks restricts opportunities to connect biological concepts with contextual problems and engage in independent, active, problem-centered learning. This study aimed to develop a Problem-Based Learning-based E-Module that is valid, practical, and effective for eleventh-grade senior high school students. The study employed Research and Development using the ADDIE model, comprising analysis, design, development, implementation, and evaluation. Product validity was assessed by four subject-matter experts—two Biology lecturers from Universitas Negeri Padang and two Biology teachers from SMAN 10 Padang—and one language expert from Universitas Negeri Padang. Practicality was evaluated by two Biology teachers, eight students in a limited trial, and forty students in a field trial. Data were collected through validation sheets, practicality questionnaires, and tests measuring critical thinking and biological concept understanding. Validity and practicality data were analyzed using percentages, whereas effectiveness was examined using N-Gain, normality, homogeneity, and independent-samples t-tests. The E-Module achieved a validity score of 94.91%, indicating very high validity. Teacher practicality reached 97.50%, while limited- and field-trial scores were 94.68% and 94.18%, respectively, indicating very high practicality. Critical thinking N-Gain scores were 74.47 in the experimental class and 69.91 in the control class. Biological concept understanding scores were 73.60 and 65.07, respectively. The hypothesis test yielded $p < 0.001$. These findings demonstrate that the developed E-Module is valid, practical, and effective in improving students' critical thinking skills and biological concept understanding. The module therefore provides an accessible digital resource for implementing contextual PBL and supporting meaningful, student-centered biology learning in senior high school classrooms more consistently.

Keywords: Biology Concept Understanding; Critical Thinking Skills; E-Module; Human Circulatory System; Problem-Based Learning

INTRODUCTION

Biology learning at the senior high school level plays an important role in developing students' scientific understanding and their ability to explain various phenomena of life through scientific reasoning. Biology learning should not merely focus on memorizing facts, concepts, and biological terminology, but should also provide opportunities for students to analyze information, connect concepts, evaluate evidence, and apply scientific knowledge to real-life problems. These competencies are increasingly important in 21st-century education, which emphasizes higher-order thinking, problem solving, and the ability to use knowledge meaningfully in different contexts (Arends, 2020; OECD, 2023). Therefore, biology learning needs to be designed as an active and student-centered process that enables students to construct knowledge while developing scientific thinking skills.

One of the important competencies that needs to be developed through biology learning

is critical thinking. Critical thinking involves the ability to interpret information, analyze arguments or evidence, make inferences, evaluate information, and provide logical explanations. Facione (2023) describes critical thinking as a purposeful and self-regulatory process involving interpretation, analysis, evaluation, inference, explanation, and self-regulation. Similarly, Paul and Elder (2020) emphasize that critical thinking develops through the ability to question information, analyze arguments, examine evidence, and formulate reasoned judgments. In biology learning, these skills are particularly important because students frequently encounter complex biological phenomena that require them to establish relationships among concepts, interpret scientific information, and formulate evidence-based explanations.

In addition to critical thinking, conceptual understanding is a fundamental component of meaningful biology learning. Students are expected not only to recall definitions or biological terms but also to explain concepts, establish relationships among concepts, classify information, draw conclusions, and apply concepts in different situations. Conceptual understanding provides the foundation for students to construct new knowledge and explain biological phenomena systematically. Nurhayati et al. (2021) reported that learning emphasizing conceptual understanding produces better learning outcomes than learning that primarily focuses on information delivery. In the context of biology, critical thinking and conceptual understanding are closely interconnected because students need adequate conceptual knowledge to analyze biological problems, while critical thinking enables them to use that knowledge to explain and solve problems logically (Paul & Elder, 2020).

The human circulatory system is one of the biology topics that requires both critical thinking and conceptual understanding. The topic involves interconnected concepts, including blood components, the structure and function of the heart, blood vessels, blood circulation mechanisms, blood groups, and disorders of the circulatory system. Understanding this topic requires students to connect the structure and function of biological organs and explain how the circulatory system operates as an integrated system (Campbell et al., 2020). However, students may experience difficulties when they are required to relate physiological processes to the functions of the organs involved. Putri and Widodo (2021) reported that students experience difficulties in understanding physiological concepts, particularly when they are required to connect blood circulation pathways with the functions of the organs involved.

The problem is also reflected in the learning conditions at SMAN 10 Padang. Based on the daily assessment administered to 40 students, the average score was 62.5, with most students categorized as poor, very poor, and fair, while only a small proportion achieved good and very good categories. These results indicate that students still experience difficulties in understanding the mechanism of the human circulatory system, relating organ structures to their functions, and explaining physiological processes comprehensively. The preliminary observation further showed that biology learning had utilized several learning resources, such as PowerPoint presentations, student worksheets, and available learning materials. However, these resources had not fully facilitated systematic problem-solving activities, integrated multimedia presentation, or active student involvement in constructing conceptual understanding.

The needs analysis also revealed a strong demand for more interactive and contextual digital learning materials. As many as 82.1% of students needed learning materials accompanied by pictures or illustrations, 71.8% wanted learning videos, and 94.9% stated that videos helped them understand biology materials. Furthermore, 100% of students reported that visualizations such as pictures and diagrams facilitated their understanding of biology concepts. A total of 94% of students expected more complete and interactive teaching materials, while 89% were more interested in learning when the material was presented through case studies related to everyday life. The needs analysis also indicated that students' ability to solve problems and express scientific opinions still needed improvement. Only 15.4% of students considered themselves highly capable of providing solutions when teachers

presented a problem, while only 12.8% reported being highly capable of asking in-depth questions during learning. These findings indicate the need for learning materials that combine conceptual explanations, visualization, contextual problems, and activities that explicitly train critical thinking.

One potential solution is the development of an E-Module integrated with the Problem-Based Learning (PBL) model. E-Modules provide opportunities to combine text, illustrations, videos, audio, interactive activities, and digital resources into a single learning environment. Such characteristics can facilitate students' independent learning while providing richer representations of biological concepts. Aprilia et al. (2021) emphasized the importance of readability, visual consistency, and accessibility in the design of digital learning materials. In the present study, the E-Module is developed in a digital flipbook format that incorporates images, infographics, audio narration, instructional videos, QR codes, worksheets, Quizizz-based exercises, and self-assessment through Google Forms. These features are designed to support different learning activities and make the learning experience more active, interactive, and meaningful.

The integration of Problem-Based Learning into the E-Module is particularly relevant because PBL places contextual problems at the beginning of the learning process and encourages students to investigate and construct knowledge through problem solving. Through the stages of problem orientation, organization of learning, investigation, development and presentation of solutions, and analysis and evaluation of the problem-solving process, students are encouraged to identify problems, seek relevant information, analyze evidence, discuss possible solutions, and evaluate their conclusions. Previous research has demonstrated the potential of PBL to improve students' higher-order thinking and critical thinking skills (Demirel & Dagyar, 2016; Ülger, 2018). A systematic review by Anggraeni et al. (2023) also highlights the contribution of PBL research to the development of students' critical thinking skills. In biology education, Widuri et al. (2023) reported that the implementation of PBL can improve students' critical thinking skills, while Nurwahidah (2023) found that PBL can improve biology conceptual understanding.

Previous studies have also examined the development of digital learning materials based on PBL. Anggraini and Trimulyono (2024) developed an E-Module based on PBL for virus material and reported that the product was valid, practical, and effective in training students' critical thinking skills. Sartika et al. (2024) developed a PBL-based E-Module for the human digestive system and found that the product met the criteria of validity, practicality, and effectiveness in improving critical thinking skills. Pitorini et al. (2024) also developed a biology E-Module based on PBL to improve high school students' critical thinking skills. In addition, research reported in the present study indicates that PBL-based E-Modules can support both critical thinking and conceptual understanding. These findings provide empirical support for integrating PBL into digital teaching materials.

Nevertheless, the review of previous studies indicates that research specifically developing a PBL-based E-Module for the human circulatory system while simultaneously targeting both critical thinking skills and biology conceptual understanding remains limited. Some previous studies have focused primarily on critical thinking, while others have focused on conceptual understanding or used different biology topics. The present study therefore seeks to address this gap by developing a PBL-based E-Module specifically for the human circulatory system for eleventh-grade senior high school students. The E-Module integrates contextual problems, investigation activities, worksheets, reflection, self-assessment, evaluation, multimedia elements, and digital learning resources within the PBL framework. The product is also developed based on the learning needs identified at SMAN 10 Padang. This integration represents the main novelty of the study because the E-Module is designed not only as a digital source of biological information but also as a structured learning environment for simultaneously developing critical thinking and conceptual understanding.

Based on the aforementioned problems and research gap, this study aims to develop a

Problem-Based Learning-based E-Module on the human circulatory system for eleventh-grade senior high school students and to determine its validity, practicality, and effectiveness in improving students' critical thinking skills and biology conceptual understanding. The development of this E-Module is expected to provide an interactive, contextual, and student-centered digital teaching material that can support biology teachers in implementing meaningful learning and help students develop deeper conceptual understanding and stronger critical thinking skills.

METHODS

This study employed a Research and Development (R&D) method to develop a Problem-Based Learning (PBL)-based E-Module for the human circulatory system for eleventh-grade senior high school students. The development procedure adopted the ADDIE model developed by Branch (2009), which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a systematic and flexible procedure for developing instructional products and is appropriate for the development of a PBL-based E-Module. In addition to product development, the effectiveness of the developed E-Module was examined using a quasi-experimental method with a Pretest–Posttest Control Group Design. The study involved an experimental group that received biology instruction using the developed PBL-based E-Module and a control group that used the teaching materials routinely used by the teacher at school. Both groups were administered a pretest before the learning intervention and a posttest after the learning process to determine the improvement in students' critical thinking skills and biology conceptual understanding. The experimental design was adapted from Sugiyono (2022).

The development process began with the Analysis stage, which was conducted to identify the learning needs that served as the basis for developing the E-Module. This stage included curriculum analysis, learning needs analysis, and student characteristics analysis. Curriculum analysis examined the Learning Outcomes (Capaian Pembelajaran/CP), Learning Objectives (Tujuan Pembelajaran/TP), and the human circulatory system material in accordance with the Merdeka Curriculum. Needs analysis was conducted through initial observation and questionnaires administered to 40 students to obtain information concerning the biology learning process, teaching materials currently used, students' needs, and difficulties encountered in learning the human circulatory system. Student characteristics analysis considered students' learning readiness, learning characteristics, and the availability and utilization of digital facilities at school.

The Design stage involved developing the initial design of the PBL-based E-Module based on the results of the Analysis stage. The design considered students' characteristics, the characteristics of the human circulatory system material, learning outcomes, learning objectives, and the requirements of Biology learning in Grade XI. At this stage, the researchers designed the learning objectives, material presentation based on the PBL syntax, learning activities, worksheets, exercises, evaluations, and learning reflections. The E-Module was designed in a digital flipbook format incorporating illustrations, infographics, audio narration, QR codes, and links to digital learning resources. The research instruments were also prepared at this stage, including validation sheets, practicality questionnaires, and pretest and posttest instruments for measuring students' critical thinking skills and biology conceptual understanding.

The Development stage involved realizing the initial design into a functional PBL-based E-Module. The product was developed as an interactive digital learning material containing text, images, diagrams, instructional videos, and links to learning activities and evaluations. The completed E-Module was subsequently validated by subject-matter experts and a language expert to assess the quality and feasibility of the product in terms of content, presentation, language, and conformity with the PBL learning syntax. The results of expert validation were used as a basis for revising and improving the E-Module before it was implemented in the

learning process.

The Implementation stage was conducted by testing the developed E-Module in actual biology learning activities. The product was initially subjected to a limited trial involving eight students to identify initial difficulties and obtain feedback regarding its practicality. The E-Module was subsequently implemented in a field trial involving 40 students. The effectiveness test was conducted using one experimental class and one control class. The experimental class used the PBL-based E-Module, whereas the control class used the teaching materials routinely employed by the teacher. Before the learning activities, both classes were given a pretest to determine their initial abilities. After the learning process was completed, both classes were given a posttest to measure the improvement in critical thinking skills and biology conceptual understanding. Practicality data were also obtained through questionnaires administered to teachers and students to determine the ease of use and practicality of the developed E-Module.

RESULT AND DISCUSSION

The development of the Problem-Based Learning (PBL)-based E-Module on the human circulatory system was carried out using the ADDIE model, which consists of Analysis, Design, Development, Implementation, and Evaluation stages. The results indicate that the developed E-Module met the criteria of validity, practicality, and effectiveness. The product was developed to support Biology learning for eleventh-grade senior high school students, particularly in improving critical thinking skills and biology conceptual understanding. The overall results showed that the E-Module obtained a validity score of 94.91%, teacher practicality of 97.50%, limited-trial student practicality of 94.68%, and field-trial student practicality of 94.18%. The effectiveness analysis also showed higher improvement in both critical thinking skills and biology conceptual understanding in the experimental class than in the control class.

The Analysis stage showed that the development of the E-Module was supported by the actual learning needs at SMAN 10 Padang. Curriculum analysis was conducted by examining the Learning Outcomes, Learning Objectives, and the human circulatory system material in accordance with the Merdeka Curriculum. The material was organized into three main topics, namely blood components and their functions, blood circulation, and disorders, technology, and blood transfusion. The analysis indicated that the topic required students not only to understand biological concepts but also to analyze various problems related to the human circulatory system. The needs analysis involving 40 students also showed that existing learning resources were still dominated by printed textbooks, while students needed more interactive and visually supported learning materials. These findings provided a strong basis for developing a digital E-Module that could facilitate active, contextual, and problem-centered learning.

The Design and Development stages resulted in an E-Module presented in a digital flipbook format and integrated with the PBL learning syntax. The product included illustrations, diagrams, instructional videos, audio narration, QR codes, worksheets, interactive exercises through Quizizz, and self-assessment through Google Forms. These features were arranged according to the stages of PBL so that students were not only exposed to biological information but were also encouraged to identify problems, investigate information, discuss findings, formulate solutions, and evaluate their learning. The integration of PBL with interactive E-Module features was intended to create a learning environment that could facilitate both critical thinking and conceptual understanding. The development findings are consistent with previous studies reported in the draft, which indicate that PBL-based E-Modules can produce valid, practical, and effective digital learning materials while supporting students' critical thinking and conceptual understanding.

The validation results demonstrated that the developed E-Module was highly feasible for use in Biology learning. The overall validity score was 94.91%, categorized as very valid. The validation by subject-matter experts produced a score of 94.55%, indicating that the content, presentation, visual components, and supporting digital features were appropriate.

The presentation aspect reached 96.02%, while the graphical aspect reached 89.58% and the software-engineering aspect reached 95.83%. These results indicate that the E-Module had an appropriate structure, clear presentation, readable visual components, and functional digital features. The high validity result indicates that the product had fulfilled the required quality criteria before being implemented in classroom learning. In the context of development research, validity is an essential indicator because it determines whether an educational product is appropriately designed in terms of content, construction, and learning objectives. The findings therefore support the conclusion that the developed E-Module was sufficiently valid to proceed to the practicality and effectiveness stages. The recapitulation of the validation results from each validator is presented in Table 1.

Table 1. Recapitulation of Expert Validation Results

No	Validator	Items	Score	Percentage (%)	Category	Remarks
1	Subject-Matter Expert 1	39	152/156	97.43	Very valid	Feasible for trial without substantial revision
2	Subject-Matter Expert 2	39	130/156	83.33	Very valid	Feasible for trial without substantial revision
3	Subject-Matter Expert 3	39	154/156	98.71	Very valid	Feasible for trial without substantial revision
4	Subject-Matter Expert 4	39	154/156	98.71	Very valid	Feasible for trial without substantial revision
5	Language Expert	13	64/65	98.46	Very valid	Feasible for trial without substantial revision
Total/Mean		169	654/689	94.92	Very valid	Feasible for trial

Source: Research data, 2026

The practicality results further demonstrated that the E-Module could be used effectively by both teachers and students. The teacher practicality score reached 97.50%, categorized as very practical. The two teachers gave scores of 100% and 95.00%, respectively. The assessment covered ease of use, learning-time efficiency, attractiveness, and usefulness. Ease of use and attractiveness each reached 100%, while learning-time efficiency reached 93.75% and usefulness reached 94.64%. These results indicate that the E-Module was easy to operate, did not require special training, and could be integrated into Biology learning. Teachers also considered the product helpful in presenting the human circulatory system in a more visual, systematic, and structured manner. The practicality results obtained from each teacher are summarized in Table 2.

Table 2. Recapitulation of Teacher Practicality Results

No.	Rater	Score	Percentage (%)	Category
1	Teacher 1 (WA)	80/80	100.00	Very practical
2	Teacher 2 (NN)	76/80	95.00	Very practical
Total/Mean		156/160	97.50	Very practical

Source: Research data, 2026

The practicality assessment conducted with students also produced very high results. In the limited trial involving eight students, the average practicality score was 94.68%, categorized as very practical. Students were able to follow the instructions, navigate the flipbook, engage in PBL learning activities, complete interactive exercises, and use the self-assessment features. The field trial involving 40 students produced a practicality score of 94.18%, which was also categorized as very practical. The difference between the limited trial and field trial was relatively small, indicating that the product remained practical when used by a larger number of students. The high practicality can be attributed to the combination of flipbook presentation, images, videos, diagrams, worksheets, interactive exercises, and reflection activities, which provided students with varied opportunities to read, observe, discuss, investigate, and solve contextual problems. The practicality results of the limited trial

and the field trial based on each assessment aspect are presented in Table 3 and Table 4, respectively, while Table 5 compares the results of the two trial stages.

Table 3. Student Practicality Results in the Limited Trial by Assessment Aspect

No.	Assessment Aspect	Score	Percentage (%)	Category
1	Ease of use	216/224	96.42	Very practical
2	Learning-time efficiency	90/96	93.75	Very practical
3	Attractiveness	122/128	95.31	Very practical
4	Benefits for learning	178/192	92.70	Very practical
	Total/Mean	606/640	94.68	Very practical

Source: Research data, 2026

Table 4. Student Practicality Results in the Field Trial by Assessment Aspect

No.	Assessment Aspect	Score	Percentage (%)	Category
1	Ease of use	1,084/1,120	96.78	Very practical
2	Learning-time efficiency	454/480	94.58	Very practical
3	Attractiveness	600/640	93.75	Very practical
4	Benefits for learning	876/960	91.25	Very practical
	Total/Mean	3,014/3,200	94.18	Very practical

Source: Research data, 2026

Table 5. Comparison of Student Practicality Results Between Trial Stages

No.	Trial Stage	Number of Students	Score	Maximum Score	Percentage (%)	Category
1	Limited trial	8	606	640	94.68	Very practical
2	Field trial	40	3,014	3,200	94.18	Very practical
	Total/Mean	48	3,620	3,840	94.43	Very practical

Source: Research data, 2026. The percentage in the total row is the mean of the two trial stages

The effectiveness results showed that the PBL-based E-Module contributed to the improvement of students' critical thinking skills. The average pretest score for critical thinking skills was 55.00 in the experimental class and 51.70 in the control class. After the learning intervention, the average posttest scores increased to 89.40 in the experimental class and 86.30 in the control class. The N-Gain analysis showed an average score of 74.47 for the experimental class, categorized as high, whereas the control class obtained an N-Gain score of 69.91, categorized as moderate. The higher N-Gain obtained by the experimental class indicates that students who learned using the PBL-based E-Module experienced greater improvement in critical thinking skills than students who learned using the conventional teaching materials.

The improvement in critical thinking can be explained by the characteristics of PBL, which places problems as the starting point of learning. Through problem orientation, learning organization, investigation, presentation of findings, and evaluation, students are encouraged to identify relevant information, analyze relationships among concepts, formulate solutions, and evaluate their conclusions. Such activities are closely related to the critical thinking indicators used in this study, namely interpretation, analysis, inference, evaluation, and explanation. Facione emphasizes that critical thinking involves interpreting, analyzing, evaluating, inferring, and explaining information to produce logical reasoning. Therefore, the integration of PBL into the E-Module provided students with repeated opportunities to practice these skills during the learning process. The use of illustrations, stimulating questions, structured activities, and flipbook presentation also supported students in understanding biological phenomena that may otherwise be abstract.

The statistical analysis provided further evidence of the effectiveness of the E-Module in improving critical thinking skills. The Shapiro–Wilk normality test showed that the significance values for the pretest and posttest data of both groups were greater than 0.05, indicating that the data were normally distributed. The subsequent hypothesis test produced a significance value of 0.000, which was lower than the 0.05 significance level. The result indicates a statistically significant difference in critical thinking improvement between the experimental and control classes. Therefore, the research hypothesis was accepted, indicating that the PBL-

based E-Module had a significant positive effect on students' critical thinking skills in learning the human circulatory system. This finding is consistent with the previous studies cited in the draft, particularly Saputri et al. (2023), which reported that PBL can improve critical thinking by providing students with active involvement in the learning process, and Rahmawati et al. (2024), which reported the effectiveness of PBL-based E-Modules in improving critical thinking and conceptual understanding in Biology learning.

The effectiveness of the E-Module was also evident in students' biology conceptual understanding. The average pretest score for conceptual understanding was 65.19 in the experimental class and 61.19 in the control class. After the intervention, the average posttest score increased to 90.50 in the experimental class and 86.68 in the control class. The N-Gain score of the experimental class was 73.60, categorized as high, while the control class obtained 65.07, categorized as moderate. These results indicate that both groups experienced improvement, but the improvement in the experimental class was greater than that in the control class.

The improvement in conceptual understanding can be attributed to the way the E-Module presented biological concepts through contextual problems and PBL activities. Students were required to identify problems, search for relevant information, discuss the findings, and formulate solutions based on biological concepts. This learning process encouraged students to connect newly acquired information with their existing knowledge rather than merely memorize biological facts. Consequently, students were provided with opportunities to develop a deeper understanding of the relationships among concepts within the human circulatory system. This result is also consistent with previous research identified in the draft. Mu'asaroh (2023) developed a PBL E-Module focusing on critical thinking and conceptual understanding, while Nurfadilah et al. (2025) reported that a PBL-based flipbook E-Module was valid, practical, and effective in improving students' conceptual understanding.

The hypothesis test for biology conceptual understanding also showed a significant difference between the experimental and control classes. The prerequisite analysis indicated that the data were normally distributed and homogeneous. The Levene's test produced a significance value of 0.302, which was greater than 0.05, indicating homogeneous variances. The subsequent Independent Samples t-test produced a significance value of 0.000 with a t-value of -24.537 and degrees of freedom of 78. Because the significance value was lower than 0.05, the null hypothesis was rejected and the research hypothesis was accepted. Thus, the PBL-based E-Module had a significant positive effect on students' biology conceptual understanding in the human circulatory system.

Overall, the findings demonstrate that the PBL-based E-Module was not only feasible and practical but also effective in supporting the development of both critical thinking skills and biology conceptual understanding. The effectiveness of the product can be understood from the combination of the PBL learning process and the interactive characteristics of the E-Module. PBL provided a structured learning process centered on contextual problems, investigation, discussion, and solution development, while the digital E-Module provided visual, verbal, and interactive representations that supported students throughout the learning process. This combination created opportunities for students to actively construct knowledge and apply biological concepts to meaningful problems. The finding is consistent with the research reviewed in the draft, which shows that PBL-based E-Modules generally demonstrate positive effects on Biology learning, particularly in critical thinking and conceptual understanding.

The results also strengthen the position of the present study in relation to previous research. Anggraini and Trimulyono (2024) developed a PBL-based E-Module on virus material and reported that the product was valid, practical, and effective in training critical thinking skills. Sartika et al. (2024) similarly developed a PBL-based E-Module on the human digestive system and reported positive results for critical thinking. Mu'asaroh (2023) is particularly relevant because the study integrated critical thinking and conceptual understanding, while

Yuniarti et al. (2025) demonstrated the potential of digital PBL-based E-Modules to improve critical thinking and collaboration. Nurfadilah et al. (2025) further demonstrated the effectiveness of a PBL-based flipbook E-Module in improving conceptual understanding. The present study extends these findings by integrating critical thinking and biology conceptual understanding within a PBL-based E-Module specifically designed for the human circulatory system and equipped with audio narration, instructional videos, QR codes, worksheets, interactive Quizizz exercises, and Google Forms-based self-assessment.

Thus, the results indicate that the developed PBL-based E-Module achieved the three main criteria of a quality educational product: validity, practicality, and effectiveness. The high validity and practicality scores demonstrate that the product was appropriate and feasible for classroom use, while the N-Gain and hypothesis-testing results demonstrate its effectiveness in improving students' critical thinking skills and biology conceptual understanding. These findings support the use of the developed E-Module as an alternative digital teaching material for learning the human circulatory system in Grade XI Biology. Nevertheless, the implementation still requires adequate digital devices, stable internet access, and clear instructions for learning activities and assessment features to ensure optimal use in classroom settings.

CONCLUSION

The development of the Problem-Based Learning (PBL)-based E-Module on the human circulatory system for eleventh-grade senior high school students resulted in a digital learning material that met the criteria of validity, practicality, and effectiveness. The E-Module was developed using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The product was designed in a digital flipbook format and integrated various learning features, including illustrations, diagrams, instructional videos, audio narration, QR codes, worksheets, interactive exercises, and self-assessment activities within the PBL framework. The validation results showed that the E-Module achieved a very valid category with an overall validity score of 94.91%. The practicality assessment also indicated that the product was highly practical, with scores of 97.50% from teachers, 94.68% from students in the limited trial, and 94.18% from students in the field trial. These findings indicate that the developed E-Module was feasible and easy to use in biology learning.

The effectiveness test demonstrated that students who learned using the PBL-based E-Module experienced greater improvements in critical thinking skills and biology conceptual understanding compared to students who used conventional learning materials. The experimental class obtained higher N-Gain scores for critical thinking skills (74.47) and conceptual understanding (73.60) compared to the control class (69.91 and 65.07, respectively). Statistical analysis also showed significant differences between the two groups. Overall, the developed PBL-based E-Module can serve as an alternative digital learning material to support biology learning, particularly in the human circulatory system. The integration of contextual problems, PBL activities, multimedia components, interactive exercises, and reflection activities provides opportunities for students to actively construct knowledge, analyze biological phenomena, and develop solutions. However, successful implementation requires adequate digital facilities, stable internet access, and appropriate teacher guidance to optimize the use of the E-Module in classroom learning.

REFERENCE

- Akbar, S. (2017). *Instrumen perangkat pembelajaran*. Remaja Rosdakarya.
- Anazifa, R. D., & Djukri, D. (2019). Project-based learning and problem-based learning: Are they effective to improve student's thinking skills? *Jurnal Pendidikan IPA Indonesia*, 8(3), 346–355.
- Anderson, L. W., & Krathwohl, D. R. (2021). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Pearson Education.

- Anggraeni, D. M., Prahani, B. K., Suprpto, N., Shofiyah, N., & Jatmiko, B. (2023). Systematic review of problem-based learning research in fostering critical thinking skills. *Thinking Skills and Creativity*, 49, 101334.
- Aprilia, R., Sunardi, S., & Yushardi, Y. (2021). Pengembangan E-Modul berbasis problem-based learning pada pembelajaran sains. *Jurnal Pendidikan Fisika*, 10(1), 12–21.
- Arends, R. I. (2020). *Learning to teach*. McGraw-Hill Education.
- Badan Standar, Kurikulum, dan Asesmen Pendidikan. (2025). *Capaian pembelajaran biologi SMA Kurikulum Merdeka*. Kemendikbudristek.
- Bahi, N., & Aloysius, S. (2025). How can the development of e-modules PBL improve students' critical thinking skills and independent in biology learning? *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 11(3), 983–998
- Branch, R. M. (2009). *Instructional design: The ADDIE approach*. Springer.
- Barrows, H. S., & Kelson, A. C. (2016). *Problem-based learning in secondary education and the problem-based learning institute*. Southern Illinois University School of Medicine.
- Campbell, N. A., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Orr, R. B. (2020). *Biology (12th ed.)*. Pearson Education.
- Clark, R. C., & Mayer, R. E. (2024). *E-Learning and the Science of Instruction* (5th ed.)
- Demirel, M., & Dagyar, M. (2016). Effects of problem-based learning on attitude: A meta-analysis study. *Eurasia Journal of Mathematics, Science and Technology Education*, 12(8), 2115–2137.
- Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, 12, 43–52.
- Ennis, R. H. (2020). *Critical thinking across the curriculum: A vision*. Routledge.
- Facione, P. A. (2023). *Critical thinking: What it is and why it counts*. Insight Assessment.
- Fitriani, A., Zubaidah, S., & Hidayati, N. (2022). The quality of student critical thinking: A survey of high schools in Bengkulu, Indonesia. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 8(2), 142–149.
- Fuad, N. M., Zubaidah, S., Mahanal, S., & Suarsini, E. (2017). Improving junior high schools' critical thinking skills based on test three different models of learning. *International Journal of Instruction*, 10(1), 101–116.
- Hake, R. R. (1999). *Analyzing change/gain scores*. Indiana University, 1(1), 1–27.
- Hung, W. (2019). *Problem-based learning: A learning environment for enhancing learning transfer*. Interdisciplinary Journal of Problem-Based Learning.
- Ibrahim, M. A., Latjompoh, M., Abdul, A., Ibrahim, M., Solang, M., & Akbar, M. N. (2025). *Practicality of E-Modules Based on Problem-Based Learning (PBL) Learning Model on Digestive System Material*
- Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi. (2022). *Panduan pengembangan modul ajar Kurikulum Merdeka*. Kemendikbudristek.
- Loyens, S. M. M., Jones, S. H., Mikkers, J., & van Gog, T. (2015). Problem-based learning as a facilitator of conceptual change. *Learning and Instruction*, 38, 34–42.
- Mayer, R. E. (2020). *Multimedia learning (3rd ed.)*. Cambridge University Press.
- Mayer, R. E. (2024). The past, present, and future of the cognitive theory of multimedia learning. *Educational Psychology Review*, 36, Article 8.
- Nurhayati, N., Winarno, W., & Mulyono, M. (2021). Pengaruh pembelajaran berbasis pemahaman konsep terhadap hasil belajar biologi murid. *Jurnal Pendidikan Sains Indonesia*, 9(3), 245–254.
- Nurwahidah, N. (2023). Implementasi problem-based learning dalam meningkatkan pemahaman konsep biologi murid. *Jurnal Pendidikan Biologi Indonesia*, 9(1), 55–66.
- OECD. (2023). *PISA 2022 assessment and analytical framework*. OECD Publishing.

- Paul, R., & Elder, L. (2020). *Critical thinking: Tools for taking charge of your learning and your life*. Foundation for Critical Thinking.
- Pitorini, E., Suciati, S., & Harlita, H. (2024). Pengembangan E-Modul biologi berbasis problem-based learning untuk meningkatkan kemampuan berpikir kritis murid SMA. *Jurnal Pendidikan Biologi*, 13(1), 22–33.
- Pratiwi, R., & Setiawan, D. (2022). Analisis keterampilan berpikir kritis murid pada pembelajaran biologi SMA. *Jurnal Inovasi Pendidikan Biologi*, 6(1), 44–52.
- Purwanto. (2017). *Evaluasi hasil belajar*. Pustaka Belajar.
- Putri, A., & Widodo, A. (2021). Kesulitan murid dalam memahami konsep sistem peredaran darah manusia. *BioEdu*, 10(2), 156–165.
- Rahmawati, Y., & Ridwan, A. (2021). Problem-based learning in biology education. *Jurnal Pendidikan IPA Indonesia*, 10(3), 411–420.
- Riduwan. (2015). *Skala pengukuran variabel-variabel penelitian*. Alfabeta.
- Sartika, D., Dafrita, I. E., & Nawawi, N. (2024). Pengembangan E-Modul Berbasis *Problem Based Learning* (PBL) terhadap kemampuan berfikir kritis murid pada materi system pencernaan manusia kelas XI SMAN 1 samalantan.. *Jurnal Ilmiah Pendidikan Biologi Indonesia, BIODIK* 10(3), 311-320.
- Savery, J. R. (2015). *Overview of problem-based learning: Definitions and distinctions*. Purdue University Press.
- Suarsana, I. M., & Mahayukti, G. A. (2018). Pengembangan E-Modul berorientasi pemecahan masalah. *Jurnal Pendidikan Indonesia*, 7(2), 153–160.
- Supena, I., Darmuki, A., & Hariyadi, A. (2021). The influence of 4C (constructive, critical, creativity, collaborative) learning model on students' learning outcomes. *International Journal of Instruction*, 14(3), 873–892
- Sugiyono. (2022). *Metode penelitian kuantitatif, kualitatif, dan R&D*. Alfabeta.
- Tampubolon, M. L. V., & Sipahutar, H. (2024). Development of project-based modules to improve learning outcomes, critical thinking and problem-solving skills. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 10(2), 531–541.
- Ülger, K. (2018). The effect of problem-based learning on the creative thinking and critical thinking disposition of students in visual arts education. *Interdisciplinary Journal of Problem-Based Learning*, 12(1).
- Usman, A., Munandar, K., & Utomo, A. P. (2024). How can PBL promote critical thinking skills in biology material? A systematic literature review in reputable journals. *Research and Development in Education (RaDEn)*, 4(1), 450–464.
- Widuri, R., Ristiono, R., & Alberida, H. (2023). Penerapan problem-based learning untuk meningkatkan keterampilan berpikir kritis murid. *Jurnal Pendidikan Biologi Indonesia*, 9(2), 120–130.
- Yasa, I. K. D., Suwatra, I. I. W., & Mahadewi, L. P. P. (2021). Pengembangan E-Modul interaktif berbasis problem-based learning. *Jurnal Edutech Undiksha*, 9(1), 45–54.
- Yew, E. H. J., & Goh, K. (2016). Problem-based learning: An overview of its process and impact on learning. *Health Professions Education*, 8(1), 75–79.
- Yuniarti, Astija, Bialangi, M. S., Jamhari, M., & Tiwow, V. M. (2025). Problem-Based Learning E-Module Using HTML 5 Package Platform to Improve Critical Thinking and Collaboration Skills in Biology Lessons. *Jurnal Penelitian dan Pengembangan Pendidikan*, 9(2), 306–316.
- Yustina, Y., Syafii, W., & Vebrianto, R. (2020). The effects of blended learning and project-based learning on pre-service biology teachers' creative thinking skills. *International Journal of Instruction*, 13(2), 621–636.