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Development of E-Modules Based on Problem Based Learning (PBL) on the Circulatory System Material for Grade XI Senior High School to Improve Critical and Collaborative Thinking Skills

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Abstract: 21st century education demands students to have critical thinking and collaboration skills. However, observations in class XI of SMAN 2 Sungai Penuh revealed low levels of these skills due to the lack of relevant learning media. Therefore, PBL-based E-modules are needed. This study aims to produce a valid, practical, and effective PBL-based E-module on the circulatory system material. This research employed Research and Development (R&D) using the ADDIE model, combined with a Quasi-Experimental Design (Pretest-Posttest Control Group Design) for effectiveness testing. The research subjects were 72 eleventh-grade students of SMAN 2 Sungai Penuh, divided into an experimental class (n = 36) and a control class (n = 36), selected through cluster random sampling. Instruments included validation sheets, practicality questionnaires, critical thinking tests, and collaboration observation sheets. Data analysis used descriptive statistics for validity and practicality, while effectiveness was analyzed using N-Gain scores and Independent Sample T-Test with SPSS 26 at α=0.05. Results showed validity of 95.49% (very valid), teacher practicality of 100% and student practicality of 92.89% (very practical). Effectiveness analysis revealed significant differences between groups (t= 4.523, p < 0.001) with experimental class N-Gain of 0.72 (high) compared to control class N-Gain of 0.45 (medium). Thus, the PBL-based E-module is valid, practical, and effective in improving students' critical thinking and collaboration skills.

Keywords: Circulatory system; Collaboration; Critical thinking; E-module; PBL

Introduction

Indonesian education policy continues to adapt to changing times to develop a resilient and competent generation. Through Decree No. 032/H/KR/2024 of the Head of the Education Standards, Curriculum, and Assessment Agency, the government established learning outcomes in the Independent Curriculum, which emphasizes the development of students' knowledge, skills, and character. At the high school level, this curriculum highlights the importance of critical and collaborative thinking skills as key competencies for the 21st century (World Economic Forum, 2020).

Initial observations at SMA Negeri 2 Sungai Penuh indicate that students' critical thinking and collaborative skills remain low. Based on preliminary tests conducted in classes XI MIPA C and XI MIPA D, only 11.11% and 8.33% of students respectively achieved critical thinking criteria, while 44.44% and 47.22% were categorized as less critical. Furthermore, observations during group discussions revealed that most students tend to be passive, relying heavily on teacher explanations, and demonstrate limited active participation in collaborative

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activities. Teacher interviews confirmed that the learning media used, such as conventional student worksheets (LKPD), are not designed to foster critical thinking and collaboration skills.

Previous studies have demonstrated the effectiveness of Problem-Based Learning (PBL) in improving critical thinking skills. Arifin (2020) found that PBL significantly enhanced students' critical thinking in biology learning. Similarly, Hotimah (2020), Mawarsari & Wardani (2022), and Hidayati & Wagiran (2024) reported that PBL-based learning modules improved students' problem-solving abilities. Regarding e-modules, research by Liana et al. (2022) and Miftakhurrohmah et al. (2023) showed that interactive e-modules effectively developed students' critical thinking skills in mathematics. Prabasari & Wahyuningsih (2021) and Dayu et al. (2022) also demonstrated that PBL-integrated e-modules improved students' scientific literacy and critical thinking.

However, no research has specifically developed and tested the effectiveness of a PBL-based e-module on the Circulatory System material to improve both critical thinking and collaboration skills simultaneously in students at SMA Negeri 2 Sungai Penuh. The circulatory system is a challenging biology topic due to its abstract and complex nature, requiring learning approaches that encourage active thinking, discussion, and problem-solving.

The novelty of this research lies in the integration of PBL syntax within an interactive e-module format specifically designed to develop both critical thinking and collaboration skills on circulatory system material. This study also employs a rigorous quasi-experimental design with control group to establish the effectiveness of the developed e-module. Based on this, this study aims to develop a valid, practical, and effective Problem-Based Learning (PBL) e-module on the circulatory system to improve the critical thinking and collaborative skills of 11th-grade high school students.

Method

Research Design

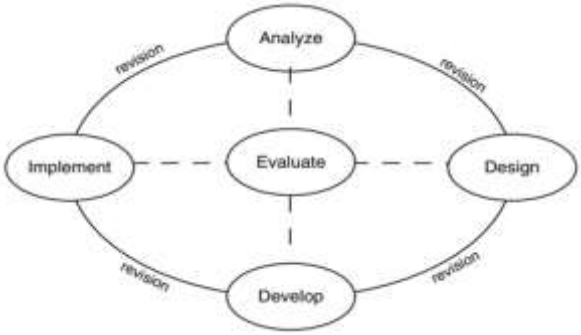

Figure 1. Stages of the ADDIE development model (Source: Branch, 2009)

This research is a type of development research or Research and Development (R&D) using the ADDIE (Analyze, Design, Development, Implementation, Evaluation) development model developed by Dick & Carry (Wardhani & Oktiningrum, 2022). The stages of the ADDIE development model are presented in Figure 1.

Quasi-Experimental Design: Pretest-Posttest Control Group

Table 1. Quasi-experimental design

Group	Treatment	Design
Experimental	PBL-based E-module	O_1 X O_2
Control	Conventional materials	O_3 — O_4

Note: O_1 and O_3 = pretest; O_2 and O_4 = posttest; X = treatment with PBL-based e-module.

Research Subjects and Sampling

This research was conducted at SMAN 2 Sungai Penuh. The population consisted of all eleventh-grade students in the science program (MIPA) studying the circulatory system material, totaling 144 students across four classes. The sample was selected using cluster random sampling technique, where two intact classes were randomly selected from the four available classes. This technique was chosen because randomization at the individual level was not feasible in the school setting. The sampling resulted in 72 students divided into two groups: Class XI MIPA C (n_1 = 36 students) as the experimental class and Class XI MIPA D (n_2 = 36 students) as the control class. The experimental class received instruction using the developed PBL-based e-module, while the control class received conventional instruction using standard student worksheets (LKPD).

Research Instruments

The instruments used in this study included: validation sheets from two media experts and two material experts to assess the feasibility of the developed e-module based on content accuracy, presentation, language, and graphic design aspects; practicality questionnaires for teachers and students to determine the ease of use and implementation of the e-module; critical thinking test instruments consisting of 10 essay questions based on Facione (2015) critical thinking indicators including interpretation, analysis, evaluation, inference, explanation, and self-regulation; and collaboration skills observation sheets adapted from the Partnership for 21st Century Skills framework, containing 15 observable indicators assessed by two trained observers during group activities. The observation sheet was used instead of a questionnaire to measure actual collaboration performance rather than self-perceived collaboration attitudes.

Data Analysis Techniques

The data analysis techniques used in this study included quantitative analysis for validity, practicality, and effectiveness assessment. All statistical analyses were conducted using SPSS 26 software at a significance level of $\alpha = 0.05$.

Validity Analysis

The e-module's validity level was determined by assessments from material experts and media experts. The validity score was calculated using the formula: Validity (%) = (Total score obtained/Maximum score) × 100%. The validity criteria are presented in Table 2. A product is considered valid if it obtains at least a "Valid" criterion (≥ 61%).

Table 2. Product validity level category

Criteria	Percentage range (%)
Invalid	0–20
Less valid	21–40
Quite valid	41–60
Valid	61–80
Very valid	81–100

Practicality of E-Modules

The practicality of the e-module was measured through response questionnaires from teachers (2 biology teachers) and students (36 students from the experimental class) after using the e-module. The practicality score was calculated using the same formula as validity. The practicality criteria are presented in Table 3. The e-module is considered practical if it obtains at least a "Practical" criterion with a percentage of ≥ 61%.

Table 3. Practicality criteria

Criteria	Percentage range (%)
Not practical	0–20
Less practical	21–40
Quite practical	41–60
Practical	61–80
Very practical	81–100

Effectiveness Analysis

The effectiveness of the e-module in improving critical thinking and collaboration skills was analyzed using the following procedures:

First, pretest and posttest were administered to both experimental and control classes. For critical thinking, the assessment used essay tests scored using a rubric. For collaboration skills, trained observers assessed students during group activities using the observation sheet.

Second, N-Gain (Normalized Gain) was calculated for each student in both classes to measure the effectiveness of improvement relative to the initial score. The N-Gain formula by Hake (1999) was used:

$$N_{Gain} = \frac{\text{Posttest score} - \text{Pretest score}}{\text{Maximum score} - \text{Pretest score}} \quad (1)$$

The N-Gain scores were categorized according to the criteria in Table 4.

Table 4. N-Gain score categories

N-Gain Score Range	Category
N-Gain ≥ 0.70	High
0.30 ≤ N-Gain < 0.70	Medium
N-Gain < 0.30	Low

Third, prerequisite tests were conducted before the hypothesis testing. The normality test was performed using Shapiro-Wilk test to determine whether the N-Gain data were normally distributed ($p > 0.05$). The homogeneity test was performed using Levene's test to determine whether the variances of the two groups were homogeneous ($p > 0.05$).

Fourth, hypothesis testing was conducted using Independent Sample T-Test to compare the mean N-Gain scores between the experimental class and control class. This test was appropriate because the two groups were independent (different students) and the comparison was made between groups, not within the same group. The hypothesis was:

H_0: There is no significant difference in N-Gain scores between the experimental and control classes.

H_1: There is a significant difference in N-Gain scores between the experimental and control classes.

The null hypothesis (H_0) was rejected if the significance value (p-value) was less than 0.05. Additionally, Effect Size (Cohen's d) was calculated to determine the magnitude of the treatment effect, with interpretation: $d < 0.2$ (small), $0.2 \leq d < 0.8$ (medium), $d \geq 0.8$ (large).

Research Procedure

The research procedure following the ADDIE model consisted of five stages: Analyze – conducting needs analysis through teacher interviews, student questionnaires, and preliminary tests to identify problems in critical thinking and collaboration skills; Design – designing the e-module framework, learning objectives, content outline, and assessment instruments; Development – developing the PBL-based e-module and validating it with material and media experts; Implementation – implementing the e-module in the experimental class and conducting effectiveness testing with pretest-posttest control group design; and Evaluation – evaluating the validity, practicality, and effectiveness of the e-module based on collected data.

Result and Discussion

Needs Analysis

Curriculum and Material Analysis

The curriculum at SMAN 2 Sungai Penuh is an independent curriculum, and the material taught in grade XI semester 1 consists of cell and membrane transport, regulation in plants, and transport and exchange of substances in humans (circulatory system). However, there are improvements in E-modules that can facilitate students in improving their critical thinking and collaborative skills in the circulatory system material through learning activities.

Problem Analysis

Based on interviews conducted with eleventh-grade biology teachers at SMAN 2 Sungai Penuh, researchers found that students' low critical and collaborative thinking skills were due to a lack of varied learning media. The teachers stated that they had never taught students using PBL-based e-modules to improve their critical and collaborative thinking skills.

Table 5. Initial analysis of critical thinking skills of Class XI MIPA students on system material blood circulation

Classification of Values (%)	Criteria	Critical Thinking Skills (%) XI C	XI D
81–100	Very Critical	0	0
66–80	Critical	11.11	8.33
56–65	Quite Critical	19.44	16.67
41–55	Less Critical	44.44	47.22
0–40	Not Critical	25	27.77

Initial observations at Sungai Penuh 2 State Senior High School indicate that students' critical thinking and collaboration skills remain low. Most students tend to be passive, relying on teacher explanations, and are less active in group discussions.

Analysis of Student Characteristics

In biology learning, they feel that biology subjects require too much memorization and concepts that are very difficult to understand. The criteria for an E-module that is attractive to students include presenting material briefly, concisely, and clearly, using language that is easy to understand, attractive colors, and equipped with images. With the existence of the developed learning E-module, it can be an additional learning resource for students, improve critical and collaborative thinking skills, and help and facilitate students to learn anytime and anywhere, both independently and in groups.

Material Analysis

In this research, it will be conducted on the material of the circulatory system for class XI SMAN odd semester. The results of the concept analysis identified in the material of the circulatory system can be seen in Figure 2.

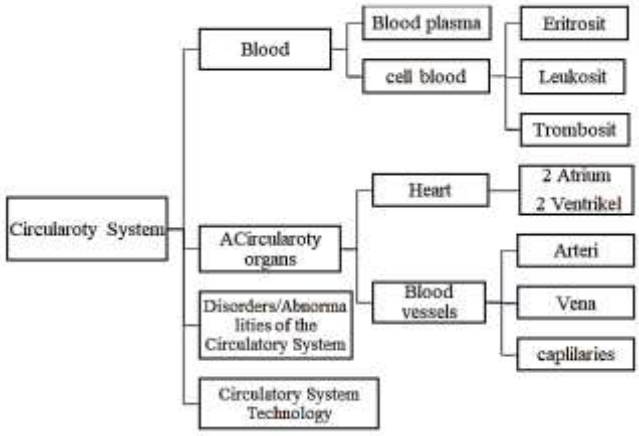

Figure 2. Circulatory system material chart

Design

E-module teaching materials for the circulatory system based on the PBL learning model to improve critical thinking skills for class XI students of SMAN 2 Sungai Penuh. Researchers designed the e-module for the circulatory system so that it can be used for class XI students of SMAN 2 Sungai Penuh who were used as samples in this study. In designing teaching materials that are oriented to the PBL learning model and indicators of critical thinking skills and making an initial design of the e-module. The design of the e-module teaching materials consists of a cover, foreword, table of contents, PBL steps, introduction, instructions for using the E-module, concept maps, learning activities (meetings 1-3), evaluation, and bibliography contained in the e-module so that the resulting teaching materials can be teaching materials. That meets the criteria for teaching materials that can be used to stimulate students' critical thinking skills. The following is a display of an e-module for stimulating students' critical thinking skills, presented in Figure 3.

Figure 3. PBL-based e-module

Development

At this stage, the e-module's feasibility was tested using expert validity instruments. The results of the validity test were revised until the product was declared suitable for use or valid. The e-module underwent several revisions, as follows:

Table 6. Suggestions and improvements from validators for PBL-based E-modules

Validator	Suggestions/input
Prof. Dr. Lufri, MS	Check again what is unnecessary, wasteful; Add Captions to images; Match the discourse to the material
Dr. dr. Elsa Yuniarti, M.Biomed AIFO-K	Improve Concept Map; Remove duplicate images; Match the image to the material; Match the discourse to the material; Add source
Nosi Qadariah, M.Pd.	Improve the layout, such as images, tables and PBL context.
Erina Erlis, M.Pd.	Correct sentence writing and check sentence writing

Revisions were made so that the media was suitable for use in accordance with the purpose of using the PBL-based mathematics e-module.

Validity of PBL-Based E-Module

The validity of PBL-based e-modules was assessed through expert validation covering four aspects: content suitability, linguistics, presentation, and graphics. The validation process involved material experts, media experts, and learning experts. The results of the validity analysis are presented in Table 7.

Table 7. Results of validity analysis of PBL-based e-modules by experts

Assessment Aspects	Validity Value (%)	Criteria
Content suitability	96.66	Very Valid
Linguistics	94.16	Very Valid
Presentation	96.88	Very Valid
Graphics	94.27	Very Valid
Average	95.49	Very Valid

Based on Table 7, the PBL-based e-module on the circulatory system material achieved an average validity score of 95.49% with very valid criteria. The content suitability aspect obtained the highest score (96.66%), indicating that the material presented in the e-module aligns well with the learning objectives and curriculum standards. This high validity score demonstrates that the e-module meets the standards for use as a learning resource in biology education (Nieveen, 1999).

The validity results are consistent with previous research by Aufa et al. (2021) who found that PBL-based e-modules on wetland environment topics achieved validity scores above 90%, indicating that the integration of problem-based learning into digital modules effectively enhances instructional quality. Similarly, Hamidi et al. (2024) reported that PBL-based e-modules developed to boost students' science process skills obtained very valid criteria with an average score of 91.5%. The high validity of PBL-based e-modules can be attributed to the systematic integration of problem scenarios that are relevant to real-world contexts, which aligns with the constructivist learning approach (Henderson et al., 2017; Savery, 2015).

The circulatory system material was specifically chosen because it contains abstract concepts that are difficult for students to understand through conventional learning methods. Syam et al. (2023) emphasized that the circulatory system material requires visualization and interactive learning approaches to enhance student comprehension. The PBL approach embedded in the e-module addresses this challenge by presenting problems related to cardiovascular health issues that students can relate to their daily lives, thereby making the abstract concepts more concrete and meaningful (Adhelacahya et al., 2023).

Practicality of PBL-Based E-Module

The practicality of the PBL-based e-module was evaluated through responses from both students and teachers. The practicality assessment focused on three aspects: attractiveness, ease of use, and benefits. The implementation was conducted in class XI C (experimental class) at SMAN 2 Sungai Penuh. The results of the practicality analysis are presented in Table 8.

Table 8. Results of practicality analysis of PBL-based e-modules

Assessment aspects	Student (%)	Teacher (%)	Criteria
Attractiveness	95.31	100.00	Very practical
Ease of use	93.35	100.00	Very practical
Benefits	90.03	100.00	Very practical
Average	92.89	100.00	Very practical

The practicality assessment results showed that the PBL-based e-module achieved an average score of 92.89% from students and 100% from teachers, both categorized as very practical. The high practicality score indicates that the e-module is user-friendly and can be easily integrated into the learning process. This finding is consistent with research by Oktavia & Zulyusri (2024) which states that learning media with a high level of practicality shows an increase in the aspect of attractiveness because its appearance and presentation are able to attract the attention of users.

The attractiveness aspect received high scores from both students (95.31%) and teachers (100%), suggesting

that the visual design, color scheme, and interactive features of the e-module successfully engaged learners. Musdalifah et al. (2023) and Hidayani et al. (2024) confirmed that interactive learning media that is practical for teachers and students also has a positive effect on student motivation and interest. The integration of multimedia elements such as images, videos, and animations in the e-module enhanced the visual appeal and facilitated better understanding of the circulatory system concepts.

Furthermore, the collaborative features embedded in the PBL-based e-module facilitated group work and peer discussion among students. Le et al. (2018) emphasized that collaborative learning practices require appropriate tools and resources that enable effective student collaboration. The e-module provided structured group activities and discussion prompts that encouraged students to work together in solving problems related to the circulatory system, thereby developing their collaborative thinking skills alongside critical thinking abilities.

Effectiveness of PBL-Based E-Module

The effectiveness of the PBL-based e-module was evaluated by comparing critical thinking skills between the experimental class (using PBL-based e-module) and the control class (using conventional learning with LKPD and PPT). The critical thinking skills were measured using indicators developed by Ennis (1996), including simple explanation, building basic skills, concluding, providing further explanation, and setting strategy and tactics. The results are presented in Table 9.

Table 9. Critical thinking skills data per indicator

Indicator	Control Class		Experimental Class	
	Pretest	Posttest	Pretest	Posttest
Simple Explanation	52.41	73.10	63.57	85.71
Building Basic Skills	50.86	68.97	50	87.5
Conclude	60.69	70.34	39.29	85.71
Provide further explanation	52.59	68.97	57.14	89.29
Setting strategy and tactics	46.55	63.79	53.57	89.29

Table 10. Results of the normality test of critical thinking skills

Class	Statistics	Df	Significance	Information
Control	0.182	29	0.123	Normal
Experiment	0.157	28	0.105	Normal

Based on Table 10, the hypothesis testing results show that the Sig. (2-tailed) value is 0.000, which is less than 0.05. This indicates a significant difference in critical thinking skills between the experimental class (M = 36.89, SD = 8.20) and control class (M = 15.34, SD = 7.90). The experimental class showed substantially higher improvement in critical thinking skills compared to the control class, demonstrating the effectiveness of the PBL-based e-module.

The significant improvement in critical thinking skills can be attributed to the problem-based learning approach integrated into the e-module. Mutiara et al. (2024) conducted a systematic literature review and found that PBL is the most effective instructional approach for fostering critical thinking abilities among students. The PBL approach encourages students to actively engage with real-world problems, analyze information from multiple perspectives, and develop evidence-based solutions (Kang & Lee, 2023; Khoirulloh et al., 2024).

The development of problem-based learning e-modules enables students to solve real-world problems, and this statement is supported by Fauzi et al. (2019) and Gusman et al. (2022), who explain that implementing evaluations in PBL-based learning provides students with the opportunity to assess the success of their own strategies and revise ineffective learning processes. Meanwhile, research by Lestari et al. (2020) and Nurwidodo et al. (2023) also confirms that analyzing and evaluating the process of overcoming the problem is a crucial part of PBL syntax, playing a role in strengthening students' reasoning and reflection on the learning outcomes achieved.

The effectiveness of PBL in improving critical thinking skills is well-documented in literature. Nurhadi et al. (2022) and Pitorini et al. (2024) developed an e-module based on PBL combined with Socratic dialogue and found significant improvements in students' critical thinking skills. The combination of problem scenarios and guided questioning helps students develop deeper analytical abilities. Similarly, Ramdani et al. (2020) and Saralee et al. (2024) reported that PBL-based e-modules assisted with Articulate applications effectively improved students' critical thinking in science education.

The integration of collaborative learning features in the e-module also contributed to the development of students' thinking skills. Sanjaya et al. (2021) developed a collaborative problem-based learning (CPBL) model and found that the combination of PBL and collaborative learning effectively supports 21st-century skills including problem solving, critical thinking, and collaboration. The e-module facilitated group discussions and collaborative problem-solving activities that enhanced both critical and collaborative thinking skills among students.

PBL is also highly effective in cultivating students' soft skills, such as collaboration, teamwork, professionalism, and workplace culture where traditional lecture-based instruction falls short (Liu et

al., 2020). The scoping review by Zakaria et al. (2021) identified that effective learning behavior in PBL includes collaboration, where students need to participate equally in discussion, listen to different viewpoints, and respond professionally. These collaborative elements were incorporated into the e-module through structured group activities and peer assessment features.

Conclusion

Based on the results of the research and development, it can be concluded that the PBL-based e-module on the circulatory system material for grade XI senior high school students has met the criteria for validity, practicality, and effectiveness. The e-module achieved a validity score of 95.49% (very valid criteria) from expert validators covering content suitability, linguistics, presentation, and graphics aspects. The practicality assessment showed an average score of 92.89% from students and 100% from teachers (very practical criteria), indicating the e-module is user-friendly and can be easily integrated into the learning process. Furthermore, the effectiveness test demonstrated a significant effect ($p = 0.000 < 0.05$) in improving students' critical thinking skills, with the experimental class achieving a mean score of 36.89 compared to 15.34 in the control class. These findings indicate that the PBL-based e-module is a valid, practical, and effective learning resource for improving critical and collaborative thinking skills in biology education.

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The authors declare no conflict of interest in this research.

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