



Effectiveness of Problem-based Research Skill Development Flipped-classroom E-module for Critical Thinking and Scientific Literacy

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Abstract

This study aims to evaluate the effectiveness of a Problem-based Learning (PBL) e-module integrated with Research Skill Development (RSD) and implemented through a flipped classroom approach to enhance students' critical thinking skills and scientific literacy. The research employed a quasi-experimental design with a non-equivalent control group. The implementation was carried out at a state senior high school in Yogyakarta, involving 65 students, with 30 assigned to the control group and 35 to the experimental group. Data collection instruments included observation sheets for learning implementation and validated tests measuring critical thinking skills and scientific literacy. The data were analyzed using descriptive statistics (mean and percentage) and inferential statistics through bootstrap MANOVA followed by bootstrap ANOVA. The MANOVA analysis yielded a significance value ($p < 0.001$), indicating that the PBL-RSD e-module effectively improved both critical thinking skills and scientific literacy simultaneously. Furthermore, the bootstrap ANOVA results showed that the PBL-RSD e-module had a stronger impact on scientific literacy (57%) compared to critical thinking skills (27%). This difference is attributed to the PBL-RSD e-module's deliberate focus on information exploration, data management, and interpretation, which are the key indicators in scientific literacy. These findings suggest that the PBL-RSD e-module, implemented through a flipped classroom model, can serve as an alternative instructional resource to develop students' critical thinking and scientific literacy in biology learning.

Keywords: *Critical thinking, Flipped classroom, Problem-based learning, Research skill development, Scientific literacy*

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INTRODUCTION

Innovative learning methods have become an urgent necessity in 21st-century education to meet the demands of technology-based, student-centered, and inquiry-driven learning that enhances students' conceptual understanding and skills (Fikri et al., 2021; Kalyani, 2024; Roito et al., 2019; Pratama et al., 2025). This aligns with the objectives of science education, particularly biology, in Indonesia. The Ministry of Education and Culture (Kemendikbud, 2022) emphasizes that biology instruction should focus on developing a systematic understanding of life, integrating data, concepts, and principles while fostering skills applicable to everyday life.

Skills that correspond to the goals of 21st-century education and biology learning include critical thinking and scientific literacy. Students with critical thinking skills can make rational

decisions by selecting the best alternatives for themselves (Usman et al., 2017). Meanwhile, scientific literacy enables students to comprehend scientific principles necessary for decision-making, reflecting the interplay between scientific concepts and knowledge at both individual and environmental levels (Lubis et al., 2025; Novaristiana et al., 2019; Suwono et al., 2023). However, previous studies indicate that these skills remain suboptimal among Indonesian high school students, including those in Yogyakarta.

Research by Mayasari & Paidi (2022), revealed that the scientific literacy of 11th-grade students in public high schools in Yogyakarta falls within the moderate category, with disparities based on school popularity. Similarly, Susilawati et al., (2020) reported that high school students exhibit low (64%) and very low (15%) levels of critical thinking skills, with only 21%

achieving a moderate level. This deficiency is evident in students' inability to connect concepts with real-world problems.

One essential topic in biology is the endocrine system, which is inherently abstract and complex due to its involvement with internal bodily mechanisms that are difficult to comprehend without visualization or digital simulation, given their intangible nature (Hadiprayitno et al., 2019; Pasaribu et al., 2024). Furthermore, teachers often report skipping this topic due to limited instructional time and insufficient teaching resources, making the endocrine system an ideal subject for investigation.

The Ministry of Education and Culture (Kemendikbud, 2014) recommends Problem-Based Learning (PBL) as an instructional model. PBL emphasizes solving real-world problems to enhance critical thinking, collaboration, and problem-solving skills (Pozuelo-Muñoz et al., 2023; Raviqah et al., 2023; Savery, 2019; Uluçinar, 2023). The effectiveness of PBL can be further improved by integrating the Research Skill Development (RSD) framework developed by Willison, (2018). This framework encompasses six interconnected inquiry skills, ranging from problem formulation and data collection to analysis and communication of results (Hutagaluh et al., 2020; Willison, 2018). Al-Sarawi et al., (2011) found that combining PBL with RSD fosters investigative skills through a more autonomous learning environment.

The integration of PBL and RSD remains underexplored. Additionally, there is a need for instructional strategies that optimize this integration through effective use of technology to create active and independent learning environments. One such strategy is the flipped classroom approach, which reverses traditional learning by delivering content outside the classroom, allowing in-class time to focus on active, collaborative, and problem-solving activities (Guerrero, 2017; Ozdamli & Asiksoy,

2016; Tunggysbay et al., 2023). This approach has been shown to promote student engagement, encourage active participation, improve learning outcomes, and develop thinking skills, particularly for students who struggle with conventional learning methods (Al-Shabibi & Al-Ayasra, 2019; Ayunda et al., 2024).

Previous studies have demonstrated the effectiveness of integrating flipped classrooms with various instructional models, such as Project-Based Learning (Sholahuddin et al., 2023), STEM (Darmastuti et al., 2025), Socio-Scientific Issues (Sugrah et al., 2023) dan PBL (Sutrio et al., 2023). However, no research has specifically examined the integration of PBL and RSD within a flipped classroom framework. This represents the gap, as current approaches often provide with the problem but lack structured cognitive steps to guide students' through the complexities of data analysis and source evaluation. Therefore, this study seeks to examine the effectiveness of implementing PBL-RSD e-module combined with a flipped classroom strategy to foster students' critical thinking and scientific literacy skills, specifically within the complex context of the endocrine system subtopic. This approach provides a novel design to bridge between basic knowledge acquisition and autonomous scientific investigation.

METHOD

This study employed a quasi-experimental approach using a non-equivalent control group design (Table 1). The research took place at a state senior high school in Yogyakarta, selected due to its higher level of readiness in terms of teacher support, facilities, and openness to instructional innovation. The implementation involved 65 students from Grade 11th Science, divided into two groups: the experimental group (35 students) and the control group (30 students). The grouping was based on academic and demographic equivalence, determined through observations and interviews with teachers.

Table 1. Research design

Group	Pre-test	Treatment	Post-test
Experiment	E ₁	X ₀	E ₂
Control	C ₁	X ₁	C ₂

The procedures for the experimental and control groups were largely similar. Both groups completed a pre-test prior to the intervention and a post-test following the instructional

intervention (see Table 1). Instruction in both groups utilized the Problem-Based Learning (PBL) model as outlined by Arends (2012). The instructional steps included: (1) orienting

students to the problem, (2) organizing findings, (3) developing and presenting solutions, (4) analyzing and evaluating the problem-solving process, and (5) concluding and reflecting. The primary difference was the intervention in the experimental group, which incorporated the use of a PBL-RSD e-module combined with a flipped classroom strategy. Instruction was delivered through two face-to-face sessions.

In the experimental group, learning was divided into two phases. The pre-class phase involved uploading instructional media and materials to Google Classroom for independent study at home. Students were required to complete Activity 1, "Creating a Summary," during the first meeting. The in-class phase consisted of face-to-face instruction using the PBL-RSD e-module while discussing students' pre-class activities. In the second meeting, students were tasked with gathering factual information to solve authentic problems presented in the PBL-RSD e-module, guided by structured questions during the pre-class phase. Subsequently, the in-class phase focused on discussion and analysis to solve problems based on the information collected.

Data were obtained from critical thinking and scientific literacy test scores, adapted from Facione, (2020) and OECD, (2023) as well as observation sheets assessing instructional implementation. The test instrument comprised seven multiple-choice items and eight essay questions, validated and tested for reliability using the Quest application. The reliability coefficient was 0.71, and item fit within the Rasch model ranged from 0.80 to 1.21, indicating that the instrument provided stable and consistent measurements of critical thinking and scientific literacy skills (Subali & Suyata, 2013).

Collected data were analyzed using descriptive and inferential statistics. The analysis procedures were as follows: implementation data for the PBL-RSD e-module were determined by calculating the mean percentage of observation scores against the ideal maximum score, following the categorical interpretation proposed by Nursyahrobby & Bakar (2022). Based on this interpretation, implementation quality classified into three categories: Very Good ($77.79\% \leq X \leq 100\%$), Good ($55.57\% \leq X \leq 77.78\%$), and Fair ($33.33\% \leq X \leq 55.56\%$).

Effectiveness data were derived from pre-test and post-test scores of critical thinking and scientific literacy before and after instruction.

Skill scores were calculated as the ratio of obtained scores to total ideal scores (Dewi et al., 2023). Statistical analysis was conducted using MANOVA to assess the effectiveness of the PBL-RSD e-module implementation. Prior to analysis, all MANOVA assumptions were verified according to Tabachnick & Fidell, (2013). If assumptions were violated, a bootstrap MANOVA was employed as a robust alternative. The bootstrap method was chosen because it addresses violations of normality or homogeneity assumptions without compromising the covariance structure among variables (Konietschke et al., 2015). Furthermore, this method is superior in maintaining statistical stability and power in multivariate contexts compared to nonparametric tests (Neumayer & Plümper, 2017).

The effectiveness of the PBL-RSD e-module implementation was evaluated against a null hypothesis (H_0) stating that no significant difference exists in students' critical thinking and scientific literacy skills between the experimental group (utilizing a flipped classroom strategy), and the control group (receiving conventional instruction). Conversely, the alternative hypothesis (H_a) posited a significant difference in these competencies between the two groups. Statistical significance for the bootstrap MANOVA was at $p < 0,05$. Following a significant multivariate outcome, the analysis will proceed to univariate testing to pinpoint the specific contribution of each dependent variable to the observed group differences.

RESULT AND DISCUSSION

Observations of learning implementation presented in Table 2 illustrate teacher and student activities within the experimental group. The teacher successfully implemented all instructional components in Learning Activities 1 and 2 (100%). Meanwhile, student engagement increased in Learning Activity 2 (90.69%) compared to Activity 1 (84.17%). Although student involvement improved overall, the activity "analyzing and evaluating the problem-solving process" remained consistently categorized as poor, with a score of 66.67%. In contrast, the activity "drawing conclusions and reflecting" showed a significant improvement from 66.67% to 100%. These findings indicate that the PBL-RSD e-module integrated with a flipped classroom approach is effective for biology instruction.

Table 2. Summary of students' and teacher activity pbl using flipped classroom

Activities	Teacher Activity Implementation (%)		Student Activity Implementation (%)	
	Learning Activity 1	Learning Activity 2	Learning Activity 1	Learning Activity 2
A. Pre-Class				
Assignment	100	100	80	100
1. Introduction	100	100	93,33	100
2. Core Activities				
a. Orient students to the problem	100	100	83,33	86,67
b. Organize students for study	100	100	100	100
c. Develop and present artifacts/work	100	100	83,33	83,33
B. In-Class				
d. Analyze and evaluate the problem-solving process	100	100	66,67	66,67
e. Concluding and reflecting	100	100	66,67	100
3. Closing	100	100	100	88.89
Average	100	100	84,17	90,69
Implementation Category	Very Good			

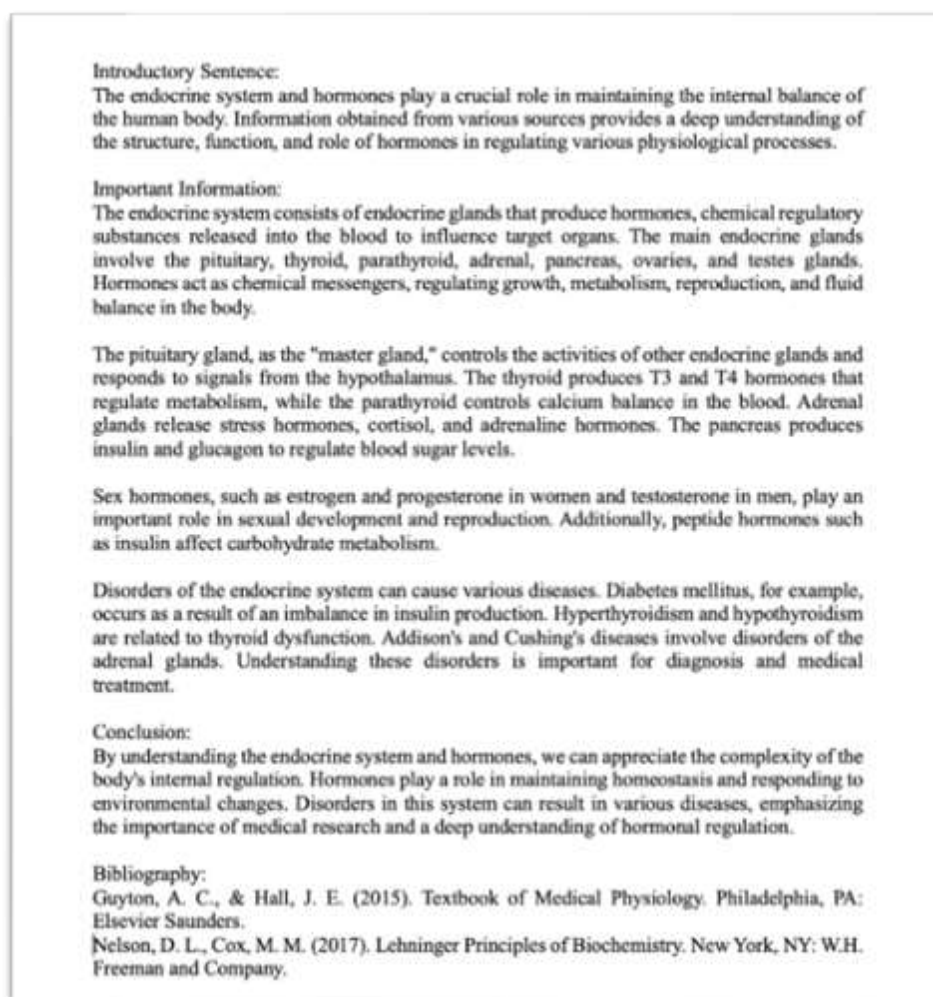


Figure 1. Example of the structured summary made by a student during the pre-class phase

The low performance in "analyzing and evaluating the problem-solving process" was evident during Activity 1, which involved summarizing (Figure 1). Students tended to copy

information verbatim rather than paraphrasing in their own words. Furthermore, during discussions and presentations, students were generally passive in responding to peers' work, although they still expressed appreciation. These observations align with Mataniari et al., (2020); Roito et al., (2019), who reported that students often perceive evaluation and reflection as less important due to minimal or unstructured feedback.

To address these challenges, the teacher provided initial stimuli such as guiding questions to initiate discussions and offered confirmation

and clarification of materials related to Activities 1 and 3 completed outside class before starting in-class sessions. Feedback and recognition of student participation helped create a positive learning environment. Previous studies by Debataraja, (2021) and Roito et al., (2019) found that constructive feedback enhances learning success and strengthens memory retention. This was evident in the current study, as students were more active in expressing opinions verbally and in writing during "drawing conclusions and reflecting" in the second session compared to the first.

Table 3. Comparison of scores

Variable	Treatment	Control		Experiment	
		M	SD	M	SD
Critical Thinking	Pre-test	42,38	12,71	43,27	16,06
	Post-test	47,62	11,46	63,67	13,57
Science Literacy	Pre-test	55,21	14,43	55,36	11,02
	Post-test	58,75	4,81	77,41	10,25

The experimental group achieved higher average scores than the control group. The mean pre-test scores for critical thinking skills were 42.38 (control) and 43.27 (experiment). After the intervention, post-test means increased to 58.75 (control) and 63.67 (experiment). Similarly, scientific literacy scores for the control group were 55.21 (pre-test) and 58.75 (post-test), while the experimental group scored 55.36 (pre-test) and 77.41 (post-test). These descriptive results suggest that implementing the PBL-RSD e-module with a flipped classroom approach positively influences students' critical thinking and scientific literacy.

To determine the magnitude of this effect, a MANOVA was conducted following Tabachnick & Fidell, (2013). Nine assumptions were considered, and the data met eight of them: (1) dependent variables which are critical thinking and scientific literacy were continuous; (2) the independent variable comprised two categorical groups (experimental using PBL-RSD e-module and control using conventional instruction); (3) observations were independent, as each student belonged to only one group; (4) the sample size ($n = 65$) was adequate and contained no missing data (see Table 5); (5) no univariate or multivariate outliers were detected, as Mahalanobis distance was less than chi-square ($8.27 < 13.82$); (6) dependent variables were multivariate normally distributed, $r(65) = 0.986$, $p < .001$, indicating high correlation (Schober et al., 2018). (7) significant

linearity ($p = .224 > .05$) between critical thinking and scientific literacy; and (8) a moderate, significant correlation $r(65) = 0.689$, $p < .001$.

One assumption was not met: homogeneity of variance-covariance matrices. Box's $M = 17.97$ ($p < .001$) indicated differing distribution structures between groups Osman, (2021). This discrepancy likely resulted from item format differences: scientific literacy items were open-ended, allowing broader response variation, whereas critical thinking items were multiple-choice, producing narrower score distributions. This variation aligns with PISA guidelines (OECD, 2017, 2023) which recommends combining multiple-choice and open-ended items to assess scientific literacy effectively. Multiple-choice items efficiently measure factual understanding, while open-ended items allow students to demonstrate analytical, synthetic, and argumentative skills based on data.

Data heterogeneity can affect the validity of MANOVA, and a preliminary test indicated violations of this assumption. To address these issues, a bootstrap MANOVA procedure was applied, following recommendations from Neumayer & Plümper (2017) and more recent applications by Saravanos et al. (2022). Bootstrapping ensures robust estimates despite abnormality and heterogeneity, particularly when sample sizes are relatively balanced (Konietschke et al., 2015; Neumayer & Plümper, 2017), allowing the results to remain statistically reliable.

Bootstrap MANOVA results (1,000 iterations) yielded Pillai's Trace = 0,571; $F(2, 62) = 41,23$; $p < 0,001$; $\eta^2 = 0,571$; observed power = 1,00 indicating statistically significant differences. Thus, the null hypothesis was rejected, confirming that the PBL-RSD e-module with the flipped classroom strategy significantly enhances critical thinking and scientific literacy simultaneously. The effect size = 0,571 reflects a large impact (Cohen et al., 2018), and observed power = 1.00 suggests minimal risk of Type II error, ensuring reliability (Tabachnick & Fidell, 2013).

Follow-up bootstrap ANOVA identified contributions of each dependent variable: critical thinking, $F(1,63) = 26,044$; $p < 0,001$; $\eta^2 = 0,292$; observed power = 0,99 dan literasi ilmiah: $F(1,63) = 83,439$; $p < 0,001$; $\eta^2 = 0,570$; observed power = 1,00. These findings align with prior research demonstrating that PBL-based e-

modules improve critical thinking (Anesa & Ahda, 2021; Dewi et al., 2023) and scientific literacy (Amaringga et al., 2021; Rahmawati et al., (2021). However, no previous studies have explicitly integrated PBL, the RSD framework, and flipped classroom strategies within an e-module, particularly for endocrine system content.

Partial eta squared values indicate that the PBL-RSD e-module with the flipped classroom strategy shows a greater influence on scientific literacy (57%) than on critical thinking (29.2%). This difference may stem from the module's emphasis on information exploration, data management, and interpretation, which are key indicators of scientific literacy. Whereas critical thinking requires logical analysis and evaluation, which showed limited improvement during student activities (Table 2).

LEARNING ACTIVITY 1: INDEPENDENT

Take a closer look at the picture (Figure 4) besides this text! When you want to find a solution, you first need to understand **what the problem is**. So, how do you do that? One simple way is to **ask questions** that help you shape a clear problem statement.

Tip Try using the **5W + 1H** formula to create your problem statement.

Once you have your **problem statement**, you can start imagining what might happen next. You might begin guessing what would happen **if something changed**. These guesses can be written as **hypotheses**. A hypothesis is your temporary answer that you can test by collecting information.

A **hypothesis** then helps you make **prediction** that can be tested!

Tip Predictions often use an "If... then..." format

Table 1. Examples of Problem Statements, Hypotheses, and Prediction

Problem Statement	Hypothesis	Prediction
Does fertilizer affect plant growth?	Fertilizer adds nutrients that plants need. So plants given fertilizer will grow better.	If I add fertilizer to chili plants, then the chili plants will grow better than chili plants without fertilizer.

After reading the explanation above, try writing your own problem statement, hypothesis, and prediction based on the phenomenon on page 12.


[Collect now](#)

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Annotations on the page:

- Image to represent the explanation text (points to the chalkboard diagram)
- Top tips as suggestions to help students' understanding (points to the tip about the 5W+1H formula)
- Integration of RSD "Embark and Clarify" (points to the table)
- Text contains a link (points to the "Collect now" button)

Figure 2. Representative page of the e-module integrates the "embark and clarify" facet of the RSD framework by providing structured scaffolding

SELF-ASSESSMENT 


Continuation of Table 2: Self-Assessment

ASPECTS OF RSD	LEVEL A	LEVEL B
D. Organizing Information	<ul style="list-style-type: none"> I used a note-taking structure, but information is still not clearly separated. Some parts of my notes are unclear or mixed together. 	<ul style="list-style-type: none"> My notes are organized in a clearly structured way. The information in my notes is connected to the main ideas.
E. Analyzing and Applying New Knowledge	<ul style="list-style-type: none"> I write key points in my notes (not copied word-for-word). My notes are still separated based on each source. 	<ul style="list-style-type: none"> I created notes that combine information from different sources. My notes show my understanding, not just repeated information.
F. Communicating Knowledge	<ul style="list-style-type: none"> My work includes a title. I included partial and/or accurate quotations from the information sources. 	<ul style="list-style-type: none"> My title matches the ideas presented in my notes. The quotations I used are accurate and appropriate.

modified from Wilson, (2016)

Follow-up action → if you marked **any items in Level A**, review your research process and information you collected.

if all your checked items are in **Level B**, **great job!** You're ready to move on to the next section.

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← RSD framework as a reflection of the investigation process

Figure 3. Representative page of the e-module integrates the “evaluate and reflect” facet of the RSD framework by providing a self-assessment table to assess information

Scientific literacy development was supported through structured learning activities in the PBL-RSD e-module, incorporating guiding questions to facilitate information acquisition, management, and evaluation (see Figures 2 and 3). These questions directed students toward solving authentic, context-based problems, consistent with Amaringga et al., (2021) who found that guiding questions enhance the ability to explain phenomena scientifically. Similarly, Fausan et al., (2021), emphasized the importance of teaching systematic processes for data collection, analysis, representation, conclusion, and interpretation. Thus, integrating PBL and RSD through guiding questions strengthens scientific literacy.

Critical thinking was fostered through activities such as summarizing and reporting analyses in the “Endocrine Gland Yearbook” (Figure 4). Linanti et al., (2021) and Sautière et al., (2019), noted that summarizing promotes critical thinking by encouraging reading, analysis, evaluation, and synthesis of concepts from diverse sources, enhancing argumentation and knowledge organization. Likewise, Pratiwi & Peniati, (2022) highlighted that opportunities for oral and written expression, supplemented by practice and evaluation, improve critical thinking. Consequently, critical thinking and scientific literacy are correlated, as Rahayuni, (2016) explained, with critical thinking serving as a key cognitive component influencing scientific literacy.

ACTIVITY 2: GROUP

Write your group's findings into the following yearbook! It is recommended to use Canva or similar application to make your yearbook layout more attractive! Happy working!

Name: Danisha (09), Farrah (10), Rahma (29), Titlis (33) Class: XI Science 5

Endocrine Gland Yearbook
Instructions: Choose one of endocrine gland that you want in this yearbook!

About me...
The parathyroid glands are four small glands located behind the thyroid gland in the neck.

The parathyroid glands are responsible for regulating **CALCIUM** levels in the blood.

The main function of the parathyroid glands is to produce **parathyroid**.

Unique facts!

1. Small size: despite being vital for body functions, parathyroid glands are very small (the size of an almond).

2. Vital hormone: Parathyroid hormone (PTH) plays critical role in maintaining calcium balance in the body.

I can't live without...

Osteoblast cells and osteoclast cells.

My greatest achievement...
Controlling the formation of vitamin D in the kidneys, which affects blood calcium levels.



My favorite quote...
Small but powerful in regulating the body's calcium balance with extraordinary precision.

One word that describes me...
Smart!

Most likely to...
Produce parathyroid hormone (PTH) which function for calcium and phosphate metabolism.

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[Collect here](#)

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Figure 4. Example of a student's artifact from an in-class group activity, where information discovered during the pre-class phase is presented in an “endocrine gland yearbook” format

This study also confirms the effectiveness of the flipped classroom strategy in improving both skills. Its implementation in the PBL-RSD e-module involved dividing content by cognitive level: lower-order thinking skills (LOTS), such as factual and procedural knowledge (e.g., understanding hormone functions), were addressed outside class, while higher-order thinking skills (HOTS), such as authentic case discussions, data evaluation, and solution communication, occurred during in-class sessions. According to Ayunda et al., (2024); Inanna et al., (2021); Kapur et al.,

(2022), alignment between pre-class and in-class activities is crucial for flipped classroom effectiveness, enabling self-paced learning and fostering proactive engagement.

In conclusion, this study confirms the effectiveness of PBL and flipped classroom strategies in biology education. It introduces a novel contribution by integrating the RSD framework into an e-module to better structure students' inquiry process. This combination enhances the development of critical thinking and scientific literacy, particularly in complex topics like the endocrine system.

The results offer practical suggestions for biology teachers, especially within the Indonesian curriculum that emphasizes increasing student independence. The results indicate that students still face challenges during the “Analyzing and Evaluating” stage. To address this, the PBL-RSD e-module was designed with deliberate scaffolding to guide students through each RSD facet. However, because these are complex skills, it is suggested that teachers also provide direct support during in-class sessions. For example, teachers can use fishbone diagrams to help students map causal factors and clarify biological concepts (Priyadi & Suyanto, 2019), or apply Socratic questioning to encourage deeper thinking about information and data (Pitorini et al., 2024). By combining the structure of an e-module with teacher guidance, students can progress more effectively from basic information collection to a more thorough understanding and evaluation of the material.

The findings demonstrate a significant impact of the PBL-RSD e-module on critical thinking and scientific literacy in biology, yet it is important to recognize its limitations. The research focused specifically to endocrine system subtopic. Nevertheless, the findings may serve as a reference for adapting similar approaches to other biology topics with comparable characteristics such as reproduction system. Additionally, the intervention took place in an urban school environment in Yogyakarta where students already had a certain level of readiness for digital learning. Future studies are recommended to explore how this e-module works in more diverse settings, such as rural areas or schools with limited technology access, to validate whether it is effective for all Indonesian students.

CONCLUSION

The effectiveness of the PBL-RSD e-module employing a flipped classroom strategy has been empirically demonstrated. Bootstrap-based MANOVA analysis indicates a significant improvement in both critical thinking skills and scientific literacy ($p < .001$). The PBL-RSD e-module with a flipped classroom approach is effective in simultaneously developing students’ skills, exerting a stronger impact on scientific literacy (57%) compared to critical thinking skills (27%). This finding suggests that the use of the PBL-RSD e-module fosters students’ ability to

comprehend, evaluate, and apply scientific information while enhancing higher-order thinking skills. These results provide practical guidance for educators to integrate technology-enhanced, inquiry-based strategies into biology instruction to promote deeper learning and transferable cognitive skills.

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