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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; Tunggyshbay 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

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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. Statical 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.

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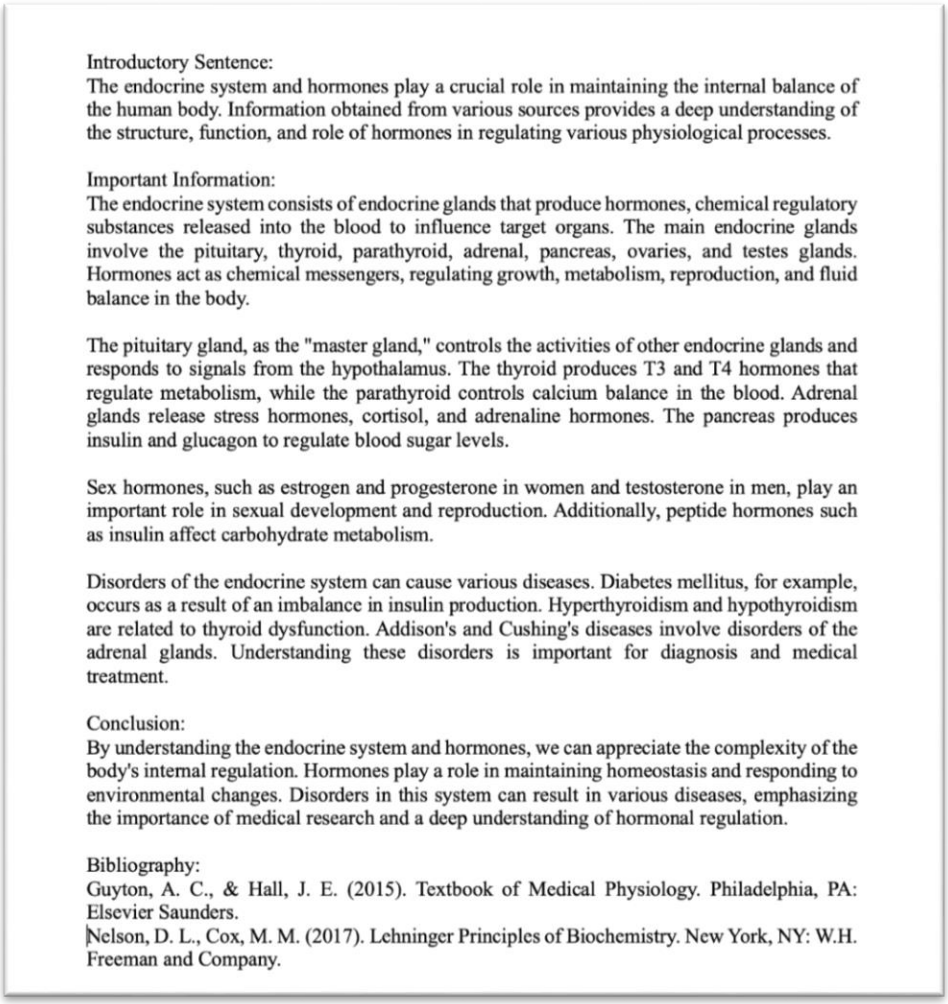
Table 2. Summary of students' and teacher activity pbl using flipped classroom

Activities	Teacher Activity Implementation (%)		Student Activity Implementation (%)	
	Learning Activity 1	Learning Activity 2	Learning Activity 1	Learning Activity 2
A. Pre-Class Assigment	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			



Introductory Sentence:
The endocrine system and hormones play a crucial role in maintaining the internal balance of the human body. Information obtained from various sources provides a deep understanding of the structure, function, and role of hormones in regulating various physiological processes.

Important Information:
The endocrine system consists of endocrine glands that produce hormones, chemical regulatory substances released into the blood to influence target organs. The main endocrine glands involve the pituitary, thyroid, parathyroid, adrenal, pancreas, ovaries, and testes glands. Hormones act as chemical messengers, regulating growth, metabolism, reproduction, and fluid balance in the body.

The pituitary gland, as the "master gland," controls the activities of other endocrine glands and responds to signals from the hypothalamus. The thyroid produces T3 and T4 hormones that regulate metabolism, while the parathyroid controls calcium balance in the blood. Adrenal glands release stress hormones, cortisol, and adrenaline hormones. The pancreas produces insulin and glucagon to regulate blood sugar levels.

Sex hormones, such as estrogen and progesterone in women and testosterone in men, play an important role in sexual development and reproduction. Additionally, peptide hormones such as insulin affect carbohydrate metabolism.

Disorders of the endocrine system can cause various diseases. Diabetes mellitus, for example, occurs as a result of an imbalance in insulin production. Hyperthyroidism and hypothyroidism are related to thyroid dysfunction. Addison's and Cushing's diseases involve disorders of the adrenal glands. Understanding these disorders is important for diagnosis and medical treatment.

Conclusion:
By understanding the endocrine system and hormones, we can appreciate the complexity of the body's internal regulation. Hormones play a role in maintaining homeostasis and responding to environmental changes. Disorders in this system can result in various diseases, emphasizing the importance of medical research and a deep understanding of hormonal regulation.

Bibliography:
Guyton, A. C., & Hall, J. E. (2015). Textbook of Medical Physiology. Philadelphia, PA: Elsevier Saunders.
Nelson, D. L., Cox, M. M. (2017). Lehninger Principles of Biochemistry. New York, NY: W.H. Freeman and Company.

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

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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.

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Bootstrap MANOVA results (1,000 iterations) yielded Pilai's Trace = 0,571; F(2, 62) = 41,23; p<0,001; η^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<001; η^2=0,292; observed power=0,99 dan litersi ilmiah: F(1,63)=83,439; p<0,001; η^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).

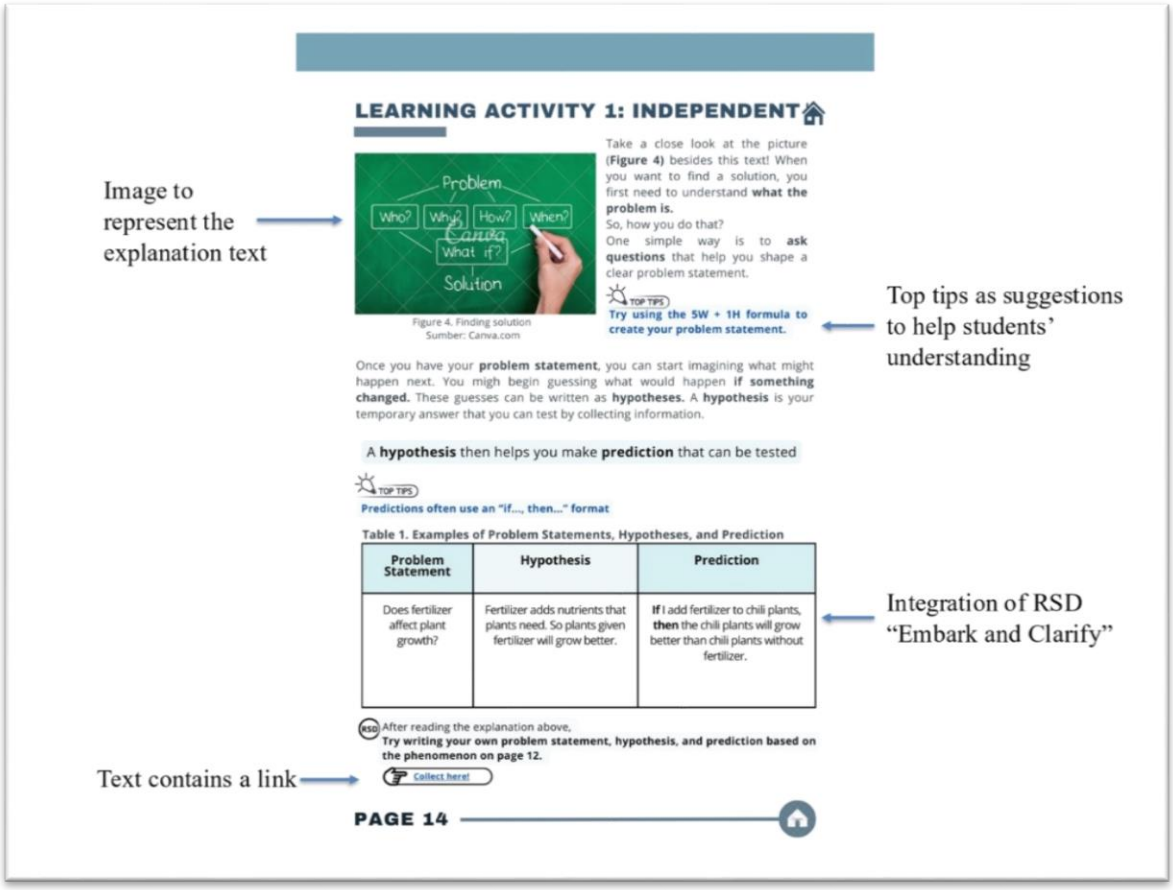

Figure 2. Representative page of the e-module integrates the "embark and clarify" facet of the RSD framework by providing structured scaffolding

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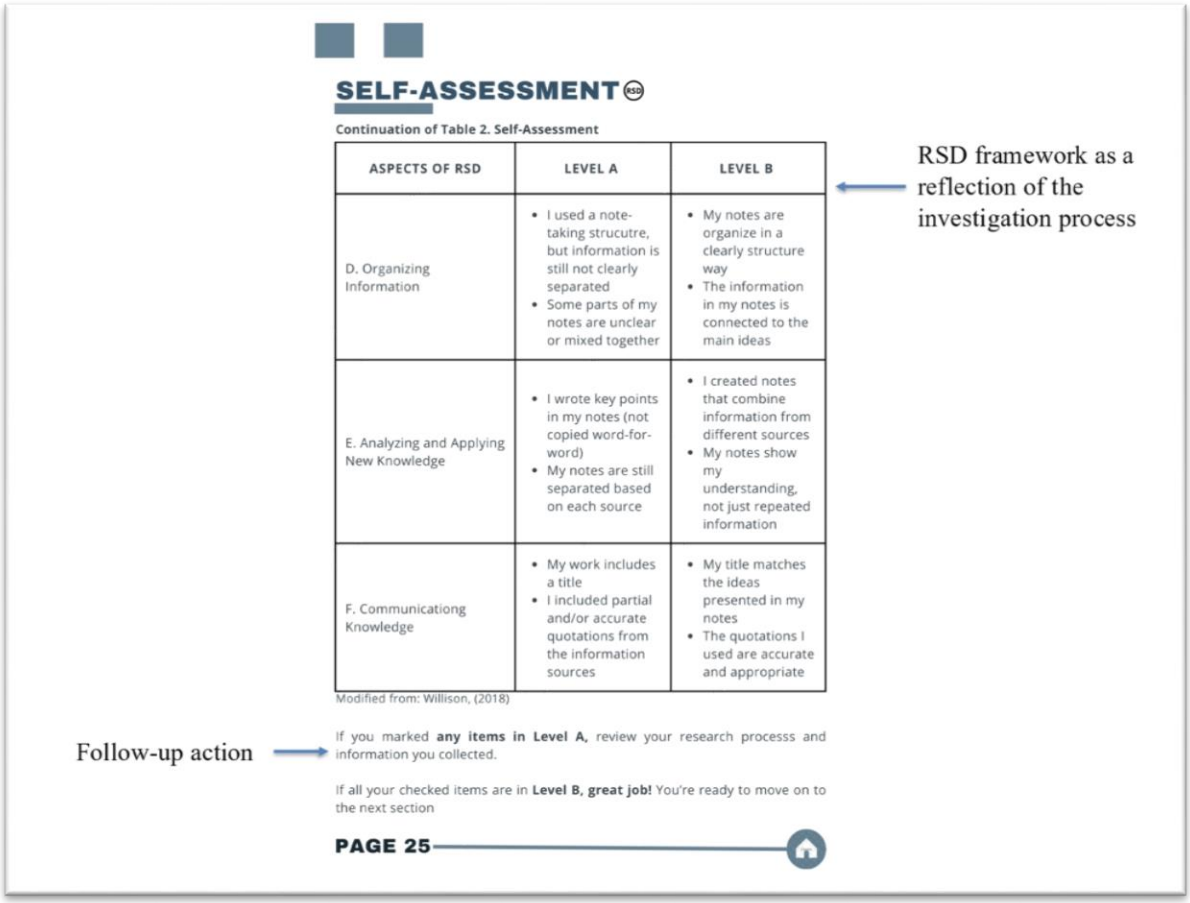

Figure 3. Representative page of the e-module integrates the "evaluate and reflect" facet of the RSD framework by providing a self-assessment table to assess information

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.

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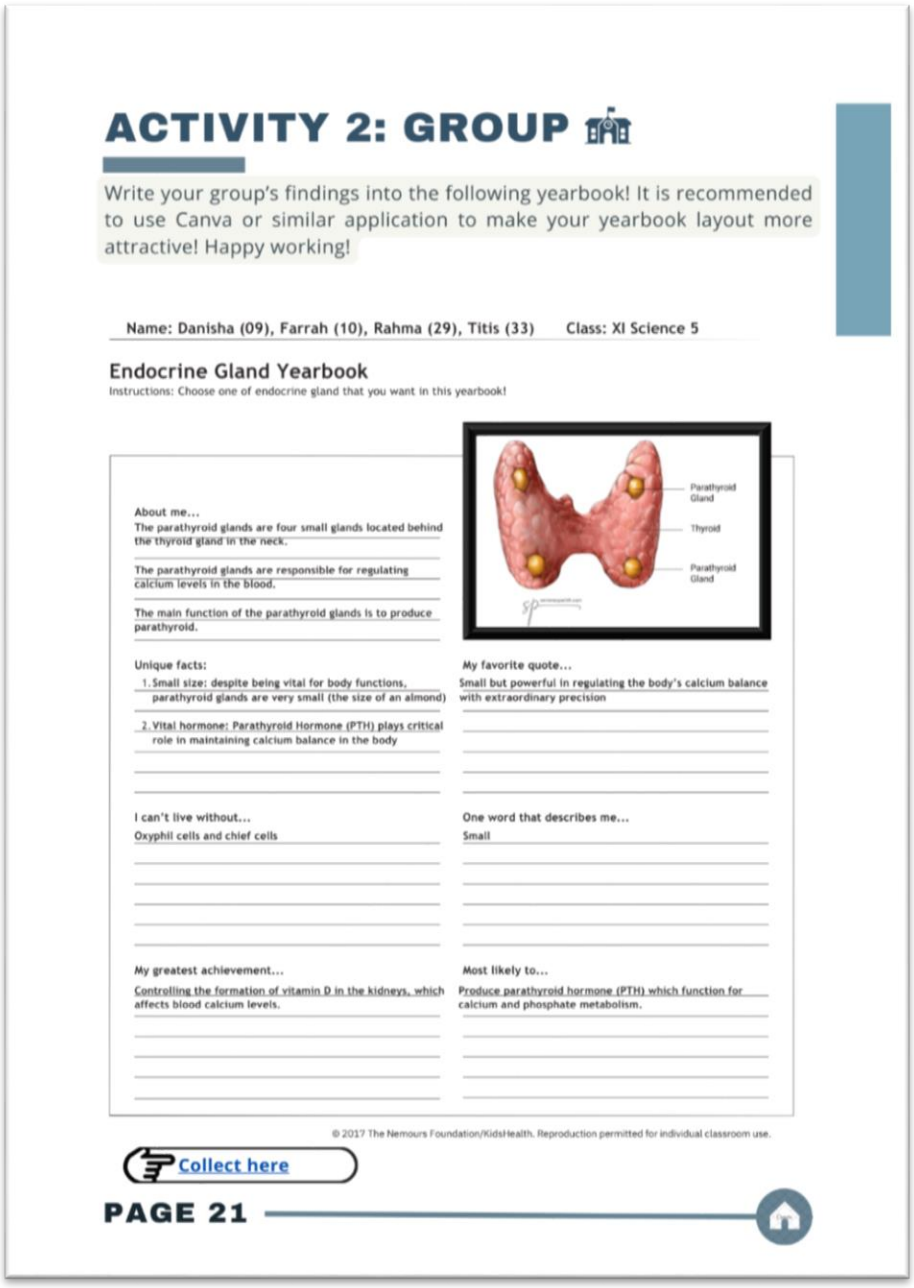

ACTIVITY 2: GROUP

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), Titis (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.

Parathyroid Gland
Thyroid
Parathyroid Gland

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

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

I can't live without...
Oxyphil cells and chief cells

One word that describes me...
Small

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

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.

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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.

REFERENCE

Al-Sarawi, S., Al-Qutayri, M., & Ismail, M. (2011). Explicit Research Skill Development within problem/project based learning approach. *ELECO 7th International on Electrical and Electronics Engineering*, 26–28. http://www.adelaide.edu.au/clpd/rsd/framework/Dec09_RS

Al-Shabibi, T. S., & Al-Ayasra, M. A. K. (2019). Effectiveness of the flipped classroom strategy in learning outcomes (bibliometric study). *International Journal of Learning, Teaching and Educational Research*, *18*(3), 96–127. https://doi.org/10.26803/ijlter.18.3.6

Amaringga, N. G., Amin, M., & Irawati, M. H. (2021). the effect of problem-based learning module containing research result to improve students' scientific literacy. *AIP Conference Proceedings*, *2330*(March). https://doi.org/10.1063/5.0043529

Anesa, D. R., & Ahda, Y. (2021). The effectiveness of problem based learning (pbl) based e-module on the classic genetic materials to improve the student's critical thinking skills. *International Journal of Social Science And Human Research*, *04*(07), 1785–1789. https://doi.org/10.47191/ijsshr/v4-i7-30

Ayunda, A. D., Hasanah, H., & Ariyanti, N. A. (2024). Development of a flipped classroom-based e-module to improve problem-solving abilities and learning independence of high school students. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *10*(2), 453–466. https://doi.org/10.22219/jpbi.v10i2.32183

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th Edition). Routledge. https://doi.org/https://doi.org/10.4324/9781315456539

Copyright © 2026, JPMS, p-ISSN: 1410-1866, e-ISSN: 2549-1458

Darmastuti, S., Isfaeni, H., & Komala, R. (2025). STEM-based flipped classroom: improve students' critical thinking skills and biological literacy in animalia material. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *11*(1), 166–178. https://doi.org/10.22219/jpbi.v11i1.39804

Debataraja, J. (2021). Analisis keterlaksanaan model pembelajaran kooperatif tipe stad dan pengaruhnya terhadap hasil belajar siswa pada materi bilangan kuantum dan bentuk orbital. *Indonesian Journal of Education Research (IJoER)*, *2*(4), 80–86. https://doi.org/10.37251/ijoer.v2i4.532

Dewi, S. K., Suwono, H., & Susanto, H. (2023). The development of electronic modules based on problem based learning integrating disaster mitigation in environmental change material to increase critical thinking skills of students. *Bioedukasi*, *21*(3), 204–210. https://doi.org/10.19184/bioedu.v21i3

Facione, Peter. A. (2020). *Critical thinking: what it is and why it counts*.

Fausan, M. M., Susilo, H., Gofur, A., Sueb, & Yusop, F. D. (2021). The scientific literacy performance of gifted young scientist candidates in the digital age. *Cakrawala Pendidikan*, *40*(2), 467–498. https://doi.org/10.21831/cp.v40i2.39434

Fikri, A. A., Nurona, A., Membimbing Diskusi Latifatus Saadah, K., Eflina Nailufa, L., Ismah Tanjak, V., Saadah, L., & Ismah, V. (2021). Keterampilan guru dalam membimbing diskusi pada pembelajaran abad 21. *Journal of Education and Teaching*, *2*(1), 1–7. https://doi.org/10.31629/jg.v2i1.119

Guerrero, W. (2017). Flipped classroom and problem-based learning in higher education: Latin-American context. *The Future of Education*. https://doi.org/DOI10.1109/INCISCOS.2017.11

Hadiprayitno, G., Muhlis, M., & Kusmiyati, K. (2019). Problems in learning biology for senior high schools in Lombok Island. *Journal of Physics: Conference Series*, *124*(1). https://doi.org/https://doi.org/10.1088/1742-6596/1241/1/012054

Hutagaluh, O., Manullang, S. O., Hamid, M., Arief, A. S., & Abdurrahman, D. (2020). How the Research Skill Development framework may be useful for Indonesian higher education learning practice. *Nidhomul Haq : Jurnal Manajemen Pendidikan Islam*, *5*(3), 347–359. https://doi.org/10.31538/ndh.v5i3.967

Inanna, Nurjannah, Ampa, A. T., & Nurdiana. (2021). Modul elektronik (e-modul) sebagai media pembelajaran jarak jauh. *Penguatan Riset, Inovasi, dan Kreativitas Peneliti di Era Pandemi Covid-19*, 1232–1241. https://ojs.unm.ac.id/semnaslemlit/article/view/25301/12678

Kalyani, L. K. (2024). The role of technology in education: Enhancing learning outcomes and 21st-century skills. *International Journal of Scientific Research in Modern Science and Technology*, *3*(4), 05–10. https://doi.org/10.59828/ijsrmst.v3i4.199

Kapur, M., Hattie, J., Grossman, I., & Sinha, T. (2022). Fail, flip, fix, and feed – Rethinking flipped learning: A review of meta-analyses and a subsequent meta-analysis. *Frontiers in Education*, *7*. https://doi.org/10.3389/feduc.2022.956416

Kementerian Pendidikan Kebudayaan Riset dan Teknologi. (2022). *Permendikbudristek Nomor 13 Tahun 2022 tentang Perubahan atas Peraturan Menteri Pendidikan dan Kebudayaan Nomor 22 Tahun 2020 Tentang Rencana Strategis Kementerian Pendidikan dan Kebudayaan Tahun 2020-2024*. https://www.kemdikbud.go.id/main/index.php/tentang-kemdikbud/rencana-strategis-renstra

Konietschke, F., Bathke, A. C., Harrar, S. W., & Pauly, M. (2015). Parametric and nonparametric bootstrap methods for general MANOVA. *Journal of Multivariate Analysis*, *140*, 291–301. https://doi.org/10.1016/j.jmva.2015.05.001

Linanti, A. T., Ridlo, S., & Harnina Bintari, S. (2021). The implementation of portfolio assessment to increase critical thinking ability for high school students on human coordination system material. *Journal of Innovative Science Education*, *10*(2), 130–136. http://journal.unnes.ac.id/sju/index.php/jise

Copyright © 2026, JPMS, p-ISSN: 1410-1866, e-ISSN: 2549-1458

Lubis, J. A., Pantiwati, Y., & Rahardjanto, A. (2025). Students' scientific literacy in critical thinking skills in science learning: A bibliometric analysis from the Scopus database. *Bioscientist : Jurnal Ilmiah Biologi*, *13*(2), 1100–1112. https://doi.org/10.33394/bioscientist.v13i2.15732

Mataniari, R., Willison, J., Hasibuan, M. H. E., Sulistiyo, U., & Dewi, F. (2020). Portraying students' critical thinking skills through Research Skill Development (RSD) framework: A case of a biology course in an Indonesian university. *Journal of Turkish Science Education*, *17*(2), 302–314. https://doi.org/10.36681/tused.2020.28

Mayasari, T., & Paidi. (2022). Analisis Kemampuan Literasi Sains Siswa Kelas XI SMA Negeri Di Kota Yogyakarta Mata Pelajaran Biologi Ditinjau dari Kefavoritan Sekolah. *Jurnal Edukasi Biologi*, *8*(1), 86–97. https://journal.student.uny.ac.id/

Neumayer, E., & Plümper, T. (2017). Robustness tests for quantitative research. In *Robustness Tests for Quantitative Research*. Cambridge University Press. https://doi.org/10.1017/9781108233590

Novaristiana, R., Rinanto, Y., & Ramli, M. (2019). Scientific literacy profile in biological science of high school students. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *5*(1), 9–16. https://doi.org/10.22219/jpbi.v5i1.7080

Nursyahrobby, M., & Bakar, A. (2022). Analisis keterlaksanaan model pembelajaran discovery learning terhadap hasil belajar pada materi larutan non-elektrolit dan elektrolit. *Panca Widha: Jurnal Praktik dan Kebijakan Indonesia*, *1*(2), 55–64. https://pwjournal.penerbitgemulun.com/index.php/pwj/article/view/11

OECD. (2017). PISA 2015 assessment and analytical framework: Science, reading, mathematics, financial literacy and collaborative problem solving (Revised ed.). In *OECD Publishing*. OECD Publishing. https://doi.org/https://doi.org/10.1787/9789264281820-en

OECD. (2023). *PISA 2022 results (Volume I): The state of learning and equity in education: I*. OECD Publishing. https://doi.org/https://doi.org/10.1787/53f23881-en

Osman, S. (2021). Factors influencing assessment conceptions among basic school teachers: A multiple analysis of variance. *International Journal of Research and Innovation in Social Science*, *5*(11), 2454–6186. https://www.rsisinternational.org/journals/ijriss/Digital-Library/volume-5-issue-11/77-86.pdf

Ozdamli, F., & Asiksoy, G. (2016). Flipped classroom approach. *World Journal on Educational Technology: Current Issues*, *8*(2), 98–105. https://doi.org/https://doi.org/10.18844/wjet.v8i2.640

Pasaribu, S., Simbolon, P., & Siregar, N. (2024). Pengaruh penggunaan model pembelajaran Picture and Picture terhadap hasil belajar Biologi siswa pada materi sistem endokrin di kelas XI IPA SMA Negeri 1 Padang Bolak Julu. *Jurnal Edugenesis*, *7*(1).

Pitorini, D. E., Suciati, S., & Harlita, H. (2024). Feasibility of an e-module based on problem-based learning combined with Socratic dialogue to enhance students' critical thinking skills. *Biosfer: Jurnal Tadris Biologi*, *15*(1), 87–100. https://doi.org/10.24042/biosfer.v15i1.22213

Pozuelo-Muñoz, J., Calvo-Zueco, E., Sánchez-Sánchez, E., & Cascarosa-Salillas, E. (2023). Science skills development through problem-based learning in secondary education. *Education Sciences*, *13*(11). https://doi.org/10.3390/educsci13111096

Pratama, F. I., Rohaeti, E., Laksono, E. W., & Apriliana, A. (2025). Literacy and research-oriented problem-based learning: exploration of implementation in classroom learning. *Jurnal Pendidikan Matematika dan Sains*, *13*(1), 70–76. https://doi.org/10.21831/jpms.v13i1.82391

Pratiwi, G., & Peniati, E. (2022). Development of e-module based on socio-scientific issues human reproductive system material to improve critical thinking ability in high school students. *Journal of Biology Education*, *11*(3), 388–396.

Copyright © 2026, JPMS, p-ISSN: 1410-1866, e-ISSN: 2549-1458

http://journal.unnes.ac.id/sju/index.php/ujbe

Priyadi, A. A., & Suyanto, S. (2019). The effectiveness of problem-based learning in Biology with fishbone diagram on critical thinking skill of senior high school students. *Journal of Physics: Conference Series*, *1397*(1). https://doi.org/10.1088/1742-6596/1397/1/012047

Rahayuni, G. (2016). Hubungan keterampilan berpikir kritis dan literasi sains pada pembelajaran IPA terpadu dengan model PBM dan STM. *Jurnal Penelitian dan Pembelajaran IPA*, *2*(2), 131–146. https://doi.org/https://doi.org/10.30870/jppi.v2i2.926

Rahmawati, J. M., Lestari, S. R., & Susilo, H. (2021). Implementation of e-module endocrine system based on problem-based learning (PBL) to improve scientific literacy and cognitive learning outcome. *AIP Conference Proceedings*, *2330*(1), 5–10. https://doi.org/10.1063/5.0043175

Raviqah, D., Rohman, F., & Lestari, S. R. (2023). Developing of electronic module on problem-based learning (PBL) to improve creative thinking skills. *BIOEDUKASI*, *21*(2), 111. https://doi.org/10.19184/bioedu.v21i2.39620

Roito, E., Solihat, R., & Wulan, A. R. (2019). Pencapaian keterampilan meneliti abad ke-21 peserta didik SMA pada pembelajaran ekosistem melalui step-by-step model experiment. *Assimilation: Indonesian Journal of Biology Education*, *2*(01), 14–18. http://ejournal.upi.edu/index.php/asimilasi

Saravanos, A., Zheng, D., & Zervoudakis, S. (2022). Measuring consumer perceived warm-glow for technology adoption modeling. *ACM International Conference Proceeding Series*, 95–102. https://doi.org/10.1145/3545922.3545938

Sautière, P. E., Blervacq, A. S., & Vizioli, J. (2019). Production and uses of e-learning tools for animal biology education at university. *European Zoological Journal*, *86*(1), 63–78. https://doi.org/10.1080/24750263.2019.1582722

Savery, J. R. (2019). Comparative pedagogical models of problem-based learning. In *The Wiley Handbook of Problem-Based Learning*. https://doi.org/10.1002/9781119173243.ch4

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation coefficients: Appropriate use and interpretation. *Anesthesia and Analgesia*, *126*(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864

Sholahuddin, A., Anjuni, N., Leny, & Faikhamta, C. (2023). Project-based and flipped learning in the classroom: A strategy for enhancing students' scientific literacy. *European Journal of Educational Research*, *12*(1), 239–251. https://doi.org/10.12973/eu-jer.12.1.239

Subali, B., & Suyata, P. (2013). Standardisasi penilaian berbasis sekolah. *Jurnal Penelitian Dan Evaluasi Pendidikan*, *17*(1), 1–18. https://doi.org/http://dx.doi.org/10.21831/pep.v17i1.1358

Sugrah, N., Suyanta, & Wiyarsi, A. (2023). Promoting students' critical thinking and scientific attitudes through socio-scientific issues-based flipped classroom. *LUMAT*, *11*(1), 140–165. https://doi.org/10.31129/LUMAT.11.1.1856

Susilawati, E., Agustinasari, A., Samsudin, A., & Siahaan, P. (2020). Analisis tingkat keterampilan berpikir kritis siswa SMA. *Jurnal Pendidikan Fisika Dan Teknologi*, *6*(1), 11–16. https://doi.org/10.29303/jpft.v6i1.1453

Sutrio, S., Busyairi, A., Doyan, A., Kosim, K., & Hikmawati, H. (2023). The effectiveness of the problem-based flipped classroom model with e-modules in improving critical thinking skills of pre-service physics teachers. *Jurnal Pendidikan Fisika Dan Teknologi*, *9*(2), 274–283. https://doi.org/10.29303/jpft.v9i2.5826

Suwono, H., Rofi'Ah, N. L., Saefi, M., & Fachrunnisa, R. (2023). Interactive socio-scientific inquiry for promoting scientific literacy, enhancing biological knowledge, and developing critical thinking. *Journal of Biological Education*, *57*(5), 944–959.

Copyright © 2026, JPMS, p-ISSN: 1410-1866, e-ISSN: 2549-1458

https://doi.org/10.1080/00219266.2021.2006270

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (Craig Campanella, Ed.; 6th ed.). Pearson.

Tunggyshbay, M., Balta, N., & Admiraal, W. (2023). Flipped classroom strategies and innovative teaching approaches in physics education: A systematic review. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(6). https://doi.org/10.29333/ejmste/13258

Uluçinar, U. (2023). The effect of problem-based learning in science education on academic achievement: A meta-analytical study. *Science Education International*, *34*(2), 72–85. https://doi.org/10.33828/sei.v34.i2.1

Usman, Mulyani, S., Susilowati, E., & Widiyaningrum, P. (2017). Analisis kesesuaian RPP terhadap pelaksanaan pembelajaran biologi dalam mengembangkan keterampilan berpikir kritis siswa. *JISE*, *6*(2). http://journal.unnes.ac.id/sju/index.php/jise

Willison, J. W. (2018). Research Skill Development spanning higher education: Critiques, curricula and connections. *Journal of University Teaching and Learning Practice*, *15*(4). https://doi.org/10.53761/1.15.4.1

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