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Research Artikel

DEVELOPMENT OF DIGITAL FLIPBOOK ECOSYSTEM (DFE) BASED PROBLEM-BASED LEARNING (PBL) TO ENHANCE CRITICAL THINKING SKILLS

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Abstract

Digital Flipbook Ecosystem (DFE) based on Problem Based Learning (PBL) was developed as an innovative learning media to facilitate the understanding of ecosystem material interactively and contextually. This study aims to develop DFE and analyze its feasibility and influence on students' critical thinking skills. The research method uses the Hannafin and Peck development model consisting of needs analysis, design, and development and implementation, followed by evaluation and revision at each stage. The results of expert validation show that DFE is very valid and suitable for use as a biology learning medium. The implementation of DFE has been shown to improve students' critical thinking skills in the indicators of organizing strategies and tactics, making further explanations, concluding, building basic skills, and providing simple explanations. These findings prove that PBL-based DFE is effective in improving students' critical thinking skills in biology learning.

Keywords*: Critical thinking; ecosystem; flipbook; problem-based learning (PBL).*

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INTRODUCTION

Learning biology in the digital era demands innovative and interactive approaches, so students can better understand complex concepts, such as ecosystems. Results of observations and needs analysis in SMA Negeri 21 Jakarta indicate that biology learning is dominated using printed books and conventional LKS (student worksheets) that tend to contain global materials and are less relevant to environmental issues around the students. Additionally, teachers are still unable to fully utilize the existing digital facilities, such as projectors, laptops, and internet access, to create more interesting and meaningful learning. Consequently, students tend to be passive, less motivated, and experience difficulties understanding ecosystem materials that are full of abstract terms and concepts (Kusmana & Anantyarta, 2025). The needs analysis also suggests that students want learning media that have attractive visualization, easy-to-access, and can assist them to think critically to solve real environmental problems (Dewi et al., 2023).

The above findings suggest the need for developing technology-based learning media that are not only presenting materials interactively but also training students to think critically through problem-based approaches. Digital Flipbook Ecosystem (DFE) based on Problem-Based Learning (PBL) is the proposed solution. The DFE combines digital features, such as animations, videos, audios, and interactive navigation in a digital book format and can be accessed through electronic devices. The PBL model is chosen due to its real problem-centered approach that trains students to identify, analyze, and look for solutions to ecosystem problems occurring in their surrounding environment (Fatimah et al., 2025). By integrating the DFE and PBL, learning is expected to be able to enhance students' engagement, deepen their concept understanding, and develop critical thinking skills that become an important requirement in 21st-century learning.

Critical thinking skills are important skills developed in biology learning, especially in understanding complex and dynamic ecosystem concepts. Critical thinking is a reflective and reasoned thinking process that aims to decide what to believe or do, emphasizing information analysis, evaluation, and synthesis (Ennis, 1985; Facione, 2013). The indicators of critical thinking skills include providing simple explanations, building basic skills, concluding, making further explanations, and organizing strategies and tactics (Ennis, 1985).

Digital learning media, such as flipbook, have been proven effective in improving students' motivation and learning outcomes, since they are able to present materials visually, interactively, and contextually (Hutahaean et al., 2019; Widyasari et al., 2021). Moreover, the PBL approach encourages students to be active in finding solutions to real problems; therefore, their critical thinking skills can be trained optimally (Heard et al., 2020; Hmelo-Silver, 2024). Previous studies indicate that PBL-based flipbook can enhance students' critical thinking skills, especially in indicators of analysis, evaluation, and problem-solving (Fadhilah & Mulyani, 2024; Ismayati & Purwanti, 2024; Nuha et al., 2021).

The current research develops a valid and suitable Digital Flipbook Ecosystem (DFE) based on Problem-Based Learning (PBL) and analyzes its effectiveness in enhancing students' critical thinking skills in ecosystem material in SMA Negeri 21 Jakarta. This study is expected to have contributions in the form of innovative digital learning media, empirical evidence on the effectiveness of PBL-based DFE in enhancing critical thinking skills, and as a reference for educators and researchers in developing technology-based learning media that are adaptive to students' needs in the digital era.

METHOD

This research was development research, or research and development with the Hannafin and Peck model that consisted of three main phases: (1) needs analysis, (2) design, and (3) development-implementation, and was equipped with evaluation and revision in each stage. The research location was in SMA Negeri 21 Jakarta with a trial subject of 60 Grade X students divided into an experimental group (30 students) and a control group (30 students). The purposive sampling

technique was used based on equality of academic ability and availability of supporting facilities.

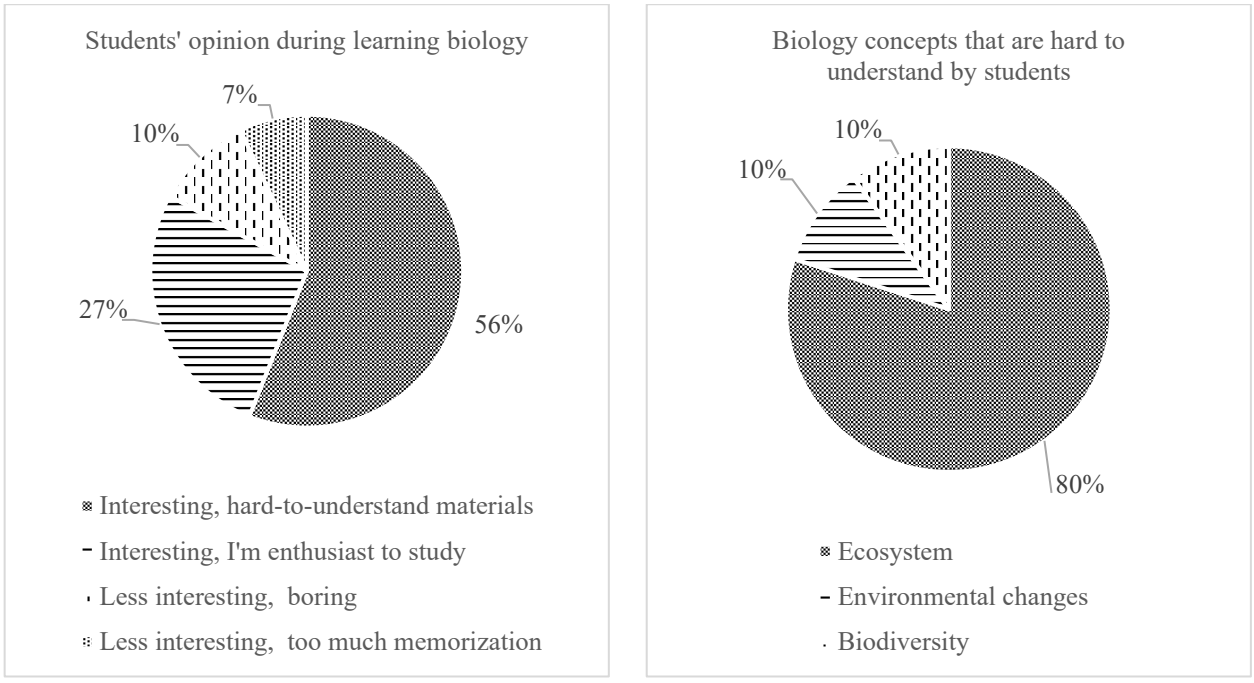
The learning materials for both groups were the same, which was ecosystem. The difference in treatment was in the learning model used. The experimental group employed the Digital Flipbook Ecosystem (DFE) based on Problem-Based Learning (PBL), whereas the control group used the official e-book issued by the Ministry of Education and Culture (*Kementerian Pendidikan dan Kebudayaan*-Kemendikbud) with a scientific approach. Teachers, time allocation, and learning objectives were maintained to be the same in both groups so that differences in the learning outcome and critical thinking skills could be attributed validly to the effectiveness of the use of the PBL-based DFE.

Data collection used needs analysis questionnaires, expert validation sheets (material, media, and language), and instruments of indicator-based critical thinking tests (Ennis, 1985). The instruments of the critical thinking test used were in the form of essays with 20 questions arranged to measure five indicators of critical thinking skills, namely providing simple explanations, building basic skills, concluding, making further explanations, and organizing strategies and tactics. The test instruments were validated by four biology education experts and tested for their reliability using the Alpha Cronbach coefficient with reliability criteria ($\alpha > 0.7$). The expert validation consisted of content, presentation, language, and graphics with a score criterion ≥3.25 (scale 1-4) (Batubara, 2021).

The implementation of the Digital Flipbook Ecosystem (DFE) was conducted for four weeks with a pretest-posttest control group. Data were analyzed quantitatively-descriptively and inferentially using the Kolmogorov-Smirnov normality test, Levene's homogeneity test, and paired and independent t-tests. The effectiveness of the intervention was measured using N-gain calculation with the following categories: high ($g \geq 0,7$), moderate ($0,3 \leq g < 0,7$), and low ($g < 0,3$).

RESULTS AND DISCUSSIONS

The development of the Digital Flipbook Ecosystem (DFE) based on Problem Based Learning (PBL) employed the Hannafin and Peck model that consisted of three main phases: needs analysis, design, and development-implementation.



a b

Figure 1. Results of Needs Analysis: a) Students' opinion during biology learning b) Biology concepts that are hard to understand by students

The needs analysis results indicate that 56% of the students considered biology learning as interesting, but it is a hard-to-undertand material, and 80% of them stated that ecosystem is the hardest material.

The design stage produced a DFE design that contains ecosystem material consisting of components of an ecosystem, units of an ecosystem, interaction between ecosystem components, energy flows, ecological pyramids, and biogeochemical cycles. The medium was developed using the Canva application for design and Fliphtml5 for digitalization. It is equipped with interactive features, such as videos, animations, navigation, and PBL-based activities.

Table 1. Results of the Media Suitability Test of the Digital Flipbook by Media Experts

Assessment Components	Requirements	Assessor				Average	Description
		1	2	3	4		
Display design	Clear instructions for use and writing	3,00	4,00	4,00	3,00	3,57	Very suitable
	Attractive design	3,00	4,00	4,00	4,00		
	The color selection is appropriate and attractive	3,00	4,00	3,00	4,00		
	DFE conformity to materials	3,00	4,00	3,00	4,00		
	Video conformity to material	3,00	3,00	4,00	3,00		
	Easy to operate	3,00	4,00	4,00	4,00		
	DFE runs smoothly and not slow	3,00	4,00	4,00	4,00		
Media Presentation	Media presentation supports student engagement	3,00	3,00	3,00	3,00	3,25	Very suitable
	Use of attractive and proportional images	3,00	3,00	3,00	4,00		
	Use of colors is appropriate	3,00	4,00	3,00	4,00		
Rata-rata						**3,41**	**Very suitable**

Based on Table 1, the validation results by media experts indicate that the DFE developed is very suitable based on the assessment components of display design and media presentation; therefore, it can be interpreted that the DFE is suitable to be used with revision.

Table 2. Material and Language Suitability Test by Material and Language Experts

Assessment Component	Statement	Assessor				Average	Description
		1	2	3	4		
Curriculum	Topics in the DFE are in accordance with learning outcomes	3,00	4,00	4,00	3,00	3,63	Very Suitable
	Topics in the DFE are in accordance with learning objectives	3,00	4,00	4,00	4,00		
Material Presentation	Complete and systematic presentation	3,00	4,00	3,00	4,00	3,44	Very Suitable
	Accurate and up-to-date material	3,00	4,00	3,00	4,00		
Material Presentation	Concepts have good depth of material	3,00	4,00	3,00	4,00		
	The material is presented with appropriate props	3,00	3,00	3,00	4,00		
Language	Clarity of instruction for use	3,00	4,00	4,00	3,00	3,69	Very Suitable
	Suitability of language to students' thinking levels	3,00	4,00	4,00	4,00		
	Politeness of language use	3,00	4,00	4,00	4,00		
	Appropriateness of text to material	3,00	4,00	4,00	4,00		
						3,58	**Very Suitable**

Based on Table 2, it is known that the ecosystem material in the DFE is suitable to be used as a medium as well as a source of biology learning. However, the experts provided criticism and suggestions so that DFE developed is suitable to be used for trial after revision. Revisions provided by each expert were improved prior to the readability test process (small group test). The small group trial involved two Grade X biology teachers of the "Merdeka" curriculum and 30 students in the academic year of 2024/2025. The test aimed to identify the readability of the use of DFE based on teachers' and students' perspectives. The results of the students' trial generated an average score of 3,44 (very suitable). The validation results indicate that the DFE is suitable to be used as a biology learning medium with minimum revision in the aspect of cover display, image description, and video navigation.

The DFE implementation was conducted with 60 Grade X students divided into two groups: an experimental group (30 students) and a control group (30 students).

Table 3. Descriptive Analysis of Critical Thinking Skills

Class		Indicator					
		Average	**Minimum Score**	**Maximum Score**	**SD**	**Gain Score**	**N-gain**
Experiment	Pre-test	84,00	50,00	92,00	21,08	20,64	49,13%
	Post-test	87,93	60,00	100,00	5,90		
Control	Pre-test	75,00	70,00	98,00	16,51	10.89	48,41%

Table 3 shows that in the pretest, both classes have a relatively closed average score. This indicates that both groups had similar initial abilities. The experimental group showed minimum and maximum scores that were higher than the control group, indicating that the use of the learning medium in the experimental class is able to significantly enhance students' critical thinking skills. The standard deviation (SD) illustrates data distribution levels relative to the average scores. Higher SD scores in the experimental group suggest that students' critical thinking skills in the group have greater variation than in the control group. Comparison of pretest and posttest scores resulted in the experimental class that used PBL-based Flipbook having a higher gain score than the control class that used e-book from the Kemendikbud with a scientific approach. This result suggests that the implementation of the PBL-based flipbook is more effective in enhancing students' critical thinking skills. The n-gain value in the experimental class was greater than in the control class. The greater the n-gain value, the more effective the learning is in enhancing students' critical thinking skills (S. Rahayu et al., 2022). A high n-gain indicates that most of the potential increase from the pretest to the maximum score has been achieved by the students (Wahyuni et al., 2025; Wilujeng et al., 2025).

Table 4. Results of Paired t-test

		Average	**t- calculation**	**t-statistic**	**df**	**α**	**Description**
DFE	Pretest	87,81	1,79	0,68	59	0,05	Differences exist
	Posttest	85,65					
E-Book	Pretest	84,00	3,06	0,68	59	0,05	Differences exist
	Posttest	87,93					

Table 4 indicates the results of the paired t-test where each group shows t-calculation values that were greater than the t-statistics. This suggests that there are differences between the average of pretest and posttest in each group that were statistically significant (Mahmudah & Subiantoro, 2025). In other words, the treatment applied to each group had a significant impact on students' learning outcome. Therefore, it can be inferred that learning applied is effective in enhancing learning outcome.

Table 5. Results of Independent t-test

	t-Calculation	**Df**	**t-Statistic**	**α**	**Description**
Posttest Control-experiment	13,95	118	1,98	0,05	There were differences in the posttest results in control and experiment classes

Table 5 presents the results of the independent t-test. Based on the table, there were

significant differences between the average posttest scores of the control group and those of the experiment group as indicated by the t-calculation values that are far greater than the t-statistics. These differences were not a coincidence, but they show that learning treatment applied in the experiment group provided a stronger impact on the enhancement of students' critical thinking skills. The PBL-based DFE not only presents materials in the form of text, but it also provides interactive visuals, animations, videos, problem starters, and investigative activities that encourage students to analyze and conclude information more actively.

Meanwhile, learning with e-book tends to be linear and focus on text. During the implementation, it was observed that students in the experimental groups were more active in asking questions, discussing, and connecting contextual problems to ecosystem concepts being studied. Teachers also recorded that group discussions were livelier, students understood the problems faster, and they were more confident in giving reasons and explanations. In contrast, students in the control group tended to be passive, dependent on the teacher's explanation, and showed less courage in expressing opinions. These findings were in line with a much sharper increase in the critical thinking indicators in the experimental group, especially in the indicators of making further explanations, and organizing strategies and tactics. Therefore, the superiority of the PBL-based DFE was not only indicated in the increase in numerical scores but was also reflected in the students' learning behavior during the learning process that, overall, showed a positive and significant change compared to the control group (Chengere et al., 2025). The results suggest that learning applied to the experimental group was more effective in enhancing students' achievement than the control group. Thus, there is an influence of the use of DFE on the experimental class compared to the use of e-book on the control class.

Table 6. Critical Thinking Skill Analysis

No	Data	Average				Gain Score	N-gain
		Pretest	SD	Posttest	SD		
1	Providing simple explanation	57,33	16,79	76,66	20,02	19,33	34%
2	Building basic skills	53,50	12,50	72,50	18,99	19,00	35%
3	Concluding	55,00	15,87	86,00	19,94	31,00	56%
4	Making further explanations	47,50	13,09	85,00	21,42	37,50	79%
5	Organizing strategies and tactics	45,00	12,73	85,00	24,04	19,33	34%

Based on Table 6, there was a consistent and significant pattern of increase in all aspects of students' critical thinking skills after the application of learning treatments. The analysis of pretest scores indicates that the initial abilities of the students were varied between indicators. The analysis results suggest that students had relatively good basic skills in providing simple explanations and concluding; however, they were weak in the aspects that demand higher-level critical thinking skills, such as organizing strategies and developing in-depth explanations.

The posttest results indicate an increase in all indicators, with a varied yet consistent increase in scores. This suggests the effectiveness of learning applied in the development of critical thinking skills. The standard deviation analysis provides an overview of the variation in ability between the students at each learning stage. In the pretest phase, the standard deviation indicates a relatively homogeneous variation in initial ability. However, in the posttest phase, the standard deviation increased, indicating greater ability after learning. It can be inferred that learning can optimize the potential of students with high abilities. However, it requires attention to ensure that students with low abilities are not left behind.

Gain score obtained indicates an increase in critical thinking skills for each indicator. It suggests that learning is the most effective in developing critical thinking skills, namely in indicators related to strategies, tactics, and in-depth explanation. However, the indicator with the lowest pretest score experienced the highest gain score, indicating that the learning succeeded in overcoming the initial weakness of the

students in the aspect. Based on the N-gain criteria, the indicator of "organizing strategies and tactics" achieved a high category of N-gain (>70%), indicating excellent learning effectiveness.

The highest effectiveness in the aspect of "organizing strategies and tactics" implies that students have succeeded in developing metacognitive skills in critical thinking, namely skills to plan, monitor, and evaluate the thinking process. This is crucial since metacognitive skills are the foundation to develop sustainable critical thinking skills and transfer learning to different contexts (Amiruddin et al., 2024; Furbani et al., 2025).

The advantages of the PBL-based DFE can be seen in its integration of interactive visuals with problem-solving scenarios that are missing in ordinary digital media; hence, students can explore the concepts independently and in more depth. DFE can also easily be replicated since it is created using simple platforms, such as Canva and FliphTML5. Moreover, its materials can be adjusted to other school contexts. Nevertheless, its implementation in real class faces several challenges, such as time limitation, teacher readiness in managing PBL, and the availability of devices and internet access. These challenges, however, can be minimized through appropriate planning and teacher's mentoring. The PBL model that is integrated into the DFE presents problems related to ecosystems that encourage students to analyze, evaluate, and look for solutions systematically (Damayanti & Raharjo, 2020; E. Rahayu et al., 2024).

The interactive features in the DFE, such as videos, animations, and navigation, allow students to explore materials independently and in-depth. The interactive digital media have been proven to be able to improve student engagement and support a meaningful knowledge construction process (Darmawan & Nawawi, 2020; H. P.S. Muttaqin et al., 2021; Hutahaean et al., 2019). The learning structure in the DFE that follows PBL syntax (problem orientation, organizing student, guiding investigation, developing work results, and evaluating) provides a systematic scaffolding to develop critical thinking skills (Lestari et al., 2023; Yusuf, 2020).

A significant increase in the indicator of "making further explanation" shows that the DFE has succeeded in developing students' metacognitive skills. PBL activities in the DFE reinforced students not only to identify problems, but also to explain the reasons, analyze assumptions, and consider the implications of solutions proposed (Endaryati et al., 2023; Ulfaa et al., 2025). The skills are the essence of critical thinking that will be useful in solving real-life problems.

The DFE effectiveness is also supported by its suitability to the characteristics of 21st-century learning, emphasizing the development of 4C skills, namely, critical thinking, communication, collaboration, and creativity. Through problem-based activities in the DFE, students not only develop critical thinking skills, but also communication skills through presentation of the investigation results and collaboration in group discussion.

The research findings confirm the constructivist theory, stating that effective learning occurs when students actively construct knowledge through interactions with meaningful learning environments. The PBL-based DFE provides a learning environment that facilitates the construction of knowledge through independent investigation, reflection, and application of concepts in a real-problem context.

CONCLUSION

The current study succeeded in developing the Digital Flipbook Ecosystem (DFE) based on Problem Based Learning (PBL) that is valid and suitable to be used as biology learning media. The results are based on the validation results by material, media, and language experts and trials by teachers and students that indicate an average score above the minimum criteria.

The implementation of the DFE has been proven to be effective in enhancing students'

critical thinking skills in ecosystem material as indicated by a significant increase in scores between pretest and posttest and higher gain scores and N-gain in the experimental class compared to the control class. The increase in critical thinking skills is especially apparent in the indicators of concluding and making further explanation, which is an indication that the PBL-based DFE is capable of training students to think analytically and logically in solving real problems related to ecosystem; thus, it is able to meet the demands of 21st-century learning which is oriented towards developing critical thinking skills.

Suggestion

Referring to the research findings, it is suggested that the PBL-based DFE to be implemented more widely in biology learning, especially for materials that require conceptual understanding and higher-level thinking skills. Teachers are expected to utilize the media to create more attractive and meaningful learning and to receive training related to the development and utilization of technology-based learning media so they can optimize their utilization in the learning process. Additionally, further development is required for interactive features in the DFE, such as, adding simulations, videos, and collaborative activities, to further support the development of students' critical thinking skills. Further research is also suggested to expand the material scope, increase the number of samples, and involve more schools so that the research findings can be generalized and can provide greater contribution to education. Evaluation and revision of learning media should be carried out periodically to ensure the quality and relevance of the media in accordance with curriculum developments and student needs.

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