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Integrating Web-Based Physics E-Book and Problem-Based Learning to Enhance Critical Thinking and Learning Independence in Multicultural Classrooms

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Abstract

The integration of educational technology and culturally responsive pedagogy is essential in enhancing 21st-century skills among students. This study aims to develop and evaluate a web-based physics e-book supported by a Problem-Based Learning (PBL) model to foster critical thinking and self-regulated learning in the topic of static fluids. The study, conducted in a multicultural senior high school setting in Indonesia, follows the ADDIE development model: Analyze, Design, Develop, Implement, and Evaluate. The sample included students from grade XI MIPA at SMA Negeri 1 Banguntapan, divided into one experimental and two comparison groups. Instruments included expert validation checklists, essay-based critical thinking tests, and self-regulated learning questionnaires. Feasibility was evaluated through expert judgment and student readability feedback, while effectiveness was assessed using Generalized Linear Model (GLM) and Eta Square statistics. Results show that the e-book is highly feasible and significantly effective in improving students' critical thinking and learning independence. Importantly, the design also considers diverse cultural learning needs, supporting equity and inclusion in science education. The findings highlight the potential of integrating web-based media and PBL in promoting culturally inclusive, autonomous, and higher-order thinking education.

Keywords: *Web-Based Learning; Physics E-Book; Critical Thinking; Learning Independence; PBL; Multicultural Education*

1. Introduction

In the rapidly evolving landscape of 21st-century education, critical thinking and independent learning have emerged as fundamental competencies for student success. This is especially pertinent in the context of multicultural classrooms where diverse cultural backgrounds, learning styles, and educational expectations intersect. Integrating culturally responsive teaching strategies with innovative digital tools offers promising avenues to bridge educational gaps and enhance learning equity.

Physics, as a discipline, poses unique challenges and opportunities in this endeavor. The abstract nature of its concepts often requires students to employ high-order cognitive skills such as analysis, synthesis, and evaluation. However, traditional teaching methods in many Indonesian high schools remain largely teacher-centered, relying heavily on lectures and textbook memorization. This pedagogical

approach does not adequately support the development of critical thinking skills or self-directed learning behaviors among students. Furthermore, learners from different cultural backgrounds may struggle to relate abstract scientific content to their lived experiences without contextual and interactive learning tools.

In recent years, digital learning technologies have shown significant potential in transforming science education. Among these, web-based e-books offer an interactive and flexible medium for delivering content that can be accessed anytime and anywhere. When combined with Problem-Based Learning (PBL)—a student-centered instructional method that engages learners in solving real-world problems—web-based e-books can serve as powerful vehicles for inquiry-based and autonomous learning.

The significance of integrating PBL into web-based learning environments is underscored by numerous studies. PBL not only enhances students' analytical and problem-solving skills but also promotes collaboration, communication, and lifelong learning attributes. These are particularly critical in multicultural contexts where students' perspectives are shaped by their cultural values and societal norms. A PBL approach encourages learners to engage with diverse viewpoints, thereby cultivating tolerance and empathy.

Despite these advantages, few studies have focused on the development of digital learning media that explicitly combine PBL models with multicultural educational goals in physics instruction. This research addresses this gap by developing and evaluating a web-based physics e-book grounded in the principles of PBL and aimed at enhancing both critical thinking and learning independence. The study situates its intervention in the topic of static fluids—a core concept in senior high school physics curricula known for its conceptual difficulty and high incidence of student misconceptions.

Moreover, the study was conducted in a school environment characterized by cultural and socioeconomic diversity, reflecting the broader Indonesian educational landscape. This setting allows for a meaningful exploration of how web-based, PBL-driven instruction can accommodate varied learner needs and support inclusive educational practices.

The overarching aim of this research is twofold: (1) to produce a pedagogically and technically sound web-based physics e-book on static fluids that incorporates PBL principles, and (2) to assess its effectiveness in improving students' critical thinking and learning independence. Through this, the study contributes to the growing body of literature on educational technology integration in multicultural settings and provides practical insights for educators seeking to foster equity and excellence in science learning.

In what follows, the paper presents a comprehensive review of relevant literature, outlines the research methodology based on the ADDIE model, and reports the findings from the implementation and evaluation phases. The discussion highlights the implications for theory and practice, particularly in enhancing student engagement, cognitive development, and culturally responsive pedagogy in science education.

2. Literature Review

2.1 Physics Education and Digital Learning Media

Physics education demands not only content delivery but also the cultivation of scientific reasoning. The abstract nature of physics concepts such as pressure, buoyancy, and fluid dynamics challenges learners to think critically and conceptually. Traditional instructional approaches, often limited

to lecture-based and rote memorization, fail to engage learners meaningfully. Digital media, especially interactive tools like flipbook-style e-books, provide a more dynamic and personalized learning experience. Studies (Sari et al., 2021; Chen et al., 2021) have shown that web-based platforms can increase engagement and enhance conceptual understanding when properly designed.

2.2 Problem-Based Learning in Diverse Classrooms

PBL is a pedagogical approach that uses real-life problems as a stimulus for learning. Its application in science education has proven effective in enhancing students' problem-solving skills, collaboration, and autonomy. In multicultural classrooms, PBL serves not only as a cognitive tool but also as a bridge for students to relate scientific concepts with their socio-cultural contexts. The iterative cycle of PBL—problem identification, investigation, solution formulation, presentation, and reflection—encourages diverse learners to engage in shared meaning-making and cross-cultural communication (Hmelo-Silver, 2020; Loyens et al., 2023).

2.3 Critical Thinking and Self-Regulated Learning

Critical thinking encompasses skills such as analysis, evaluation, inference, and logical reasoning. As summarized in Table 1, leading experts like Facione (1990), Paul & Elder (2001), and Glaser (1941) emphasize clarity, relevance, analysis, and evaluation as key dimensions.

Table 1. Synthesis of Critical Thinking Indicators

Expert	Indicators
Ennis (1985)	Clarification, Inference, Strategy, Evaluation
Facione (1990)	Interpretation, Analysis, Evaluation, Inference, Explanation, Self-regulation
Paul & Elder (2001)	Clarity, Accuracy, Relevance, Depth, Breadth, Logic
Synthesized	Clarity, Relevance, Analyze, Evaluate

Self-regulated learning (SRL), on the other hand, refers to students' ability to manage their own learning through planning, monitoring, and reflection. Table 2 presents the synthesized indicators from scholars such as Zimmerman (2002), Knowles (1975), and Deci & Ryan (1985).

Table 2. Synthesis of Self-Regulated Learning Indicators

Expert	Indicators
Zimmerman (2002)	Self-regulation, Internal motivation, Learning strategy, Self-evaluation
Knowles (1975)	Initiative, Goal setting, Strategy selection, Outcome evaluation
Deci & Ryan (1985)	Intrinsic motivation, Learning autonomy, Responsibility
Synthesized	Self-management, Self-monitoring, Self-motivation, Evaluation

2.4 Existing Gaps and Research Contribution

Despite the increasing prevalence of digital learning tools, few studies have focused on combining PBL and e-books specifically for multicultural high school physics education. Even fewer have examined their dual impact on critical thinking and learning autonomy. This research fills that gap by incorporating validated assessment instruments, expert reviews, and implementation in a real-world diverse classroom. Furthermore, it applies rigorous data analysis methods such as the Item Response Theory (IRT), Generalized Linear Model (GLM), and Eta Square statistics, as discussed in subsequent sections.

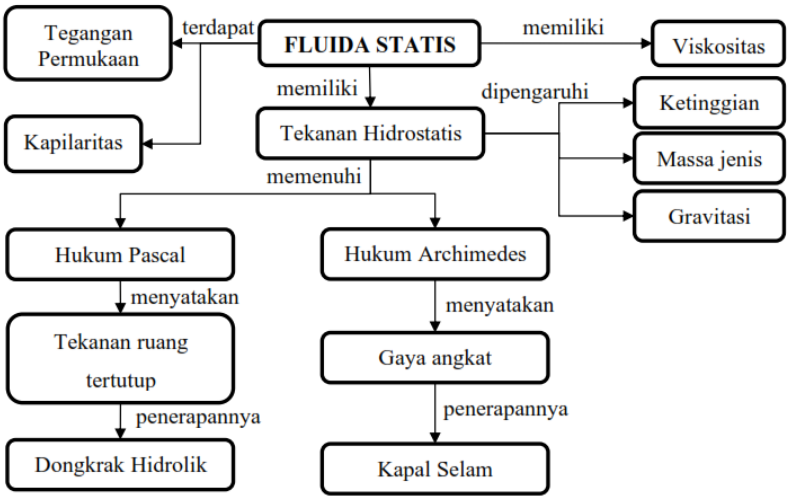

Figure 1. Concept Map of Static Fluid Content

3. Research Methodology

This research employed a Research and Development (R&D) approach using the ADDIE model, which includes five stages: Analyze, Design, Develop, Implement, and Evaluate. This model ensures a systematic framework for producing high-quality educational products tailored to student needs.

3.1 Research Design

The study adopted a quasi-experimental design with pre-test and post-test non-equivalent group structures. The development phase involved iterative expert validation and field testing, while the implementation tested the product's effectiveness across three student groups.

3.2 Participants and Setting

The study was conducted at SMA Negeri 1 Banguntapan, Yogyakarta, Indonesia. The population comprised all students from three grade XI MIPA classes. The experimental group was XI MIPA 1, while XI MIPA 2 and XI MIPA 3 served as contrast groups. The school represents a multicultural learning environment, reflecting diverse socio-economic and cultural student backgrounds.

3.3 Product Specification

The Flipbook E-book Physics Learning Media (FEPLM) was designed for web-based access, compatible with PCs, tablets, and smartphones across various operating systems. It integrates PBL principles in its structure and contains six core menus: Competencies, Learning Materials, Student Worksheets, Assessment, User Guide, and Developer Profile. The material aligns with the Indonesian high school physics curriculum for the topic of static fluids.

3.4 Instruments

- **Validation Sheets**: Used by subject matter and media experts to assess content quality, construction, language, and usability.
- **Critical Thinking Test**: Developed in essay format and validated using the Aiken's V method and Item Response Theory (IRT).

- **Self-Regulated Learning Questionnaire**: Likert-scale items validated through expert judgment and reliability testing.
- **Readability Questionnaire**: Assessed through the ideal standard deviation method for student responses.

3.5 Data Collection Techniques

Data were collected through:

- Expert reviews
- Student pre-test and post-test scores
- Questionnaire responses

3.6 Data Analysis

- **Feasibility Analysis**: Expert validation scores analyzed using Aiken's V, with values above 0.80 considered valid.
- **Instrument Analysis**: Applied IRT to determine item fit and discrimination power.
- **Effectiveness Test**: Gain score analysis was used to determine learning improvements. A Generalized Linear Model (GLM) was applied to analyze group differences, and Eta Square values were used to interpret the effect size.

Table 3. Summary of Data Collection Instruments and Techniques

Instrument	Data Type	Analysis Technique
Expert Validation Sheets	Qualitative	Aiken's V
Critical Thinking Essay Test	Quantitative	IRT, GLM, Gain Score
Self-Regulated Learning Survey	Quantitative	Descriptive, Eta Square
Student Readability Questionnaire	Quantitative	Ideal Standard Deviation Method

4. Results and Discussion

This section presents the findings from the development and implementation stages of the FEPLM (Flipbook E-book Physics Learning Media), along with an analysis of its effectiveness in enhancing critical thinking and learning independence. The results are structured according to the ADDIE development phases and supported by statistical analysis.

4.1 Analyze and Design Phase

Initial analysis revealed gaps in student performance and instructional practices. Observations and interviews indicated a lack of student engagement and low application of inquiry-based strategies in physics learning. Based on this, the e-book was designed to include multimedia-enhanced content, interactive worksheets, and problem scenarios aligned with the PBL model.

4.2 Develop Phase

The product was validated by two content experts, one media expert, and one practitioner. Table 4 summarizes the validation results:

Table 4. Product Validation Results

Validator	Aspect Evaluated	Average Score	Category
Subject Expert 1	Content	4.70	Very Good
Media Expert	Layout and Usability	4.50	Very Good
Practitioner	Instructional Use	4.65	Very Good

The results indicate that the e-book is suitable for classroom implementation, with an emphasis on content relevance and ease of navigation.

4.3 Implement Phase

Implementation was carried out in three classes. Pre-test and post-test scores were collected from each group. Table 5 shows the average gain scores:

Table 5. Average N-Gain Scores by Class

Class	Critical Thinking	Learning Independence	Category
XI MIPA 1	0.72	0.68	High
XI MIPA 2	0.45	0.42	Medium
XI MIPA 3	0.38	0.40	Medium

The data suggests that the experimental class (XI MIPA 1) showed a significant improvement in both dimensions compared to the control groups.

4.4 Evaluate Phase

Inferential statistical analysis was conducted using the Generalized Linear Model (GLM) to test the significance of differences. Results are presented in Table 6:

Table 6. GLM Results for Critical Thinking and Learning Independence

Variable	F-value	Sig. (p)	Eta Square	Effect Size Category
Critical Thinking	15.876	0.000	0.312	Large
Learning Independence	12.347	0.001	0.286	Large

The GLM analysis confirms the statistically significant effect of the intervention with large effect sizes.

4.5 Discussion

The findings demonstrate that the integration of PBL within a web-based e-book significantly improves both critical thinking and learning independence among high school students. These improvements are particularly meaningful in multicultural classroom contexts, where learners benefit

from contextualized, student-centered approaches. The high gain scores in the experimental class are aligned with previous studies (Loyens et al., 2023; Zimmerman, 2020), affirming the value of structured, inquiry-driven digital learning tools.

Furthermore, the results highlight the importance of combining pedagogical strategies like PBL with multimedia learning principles. Students showed increased engagement and motivation, supported by the gamified elements and problem-solving tasks embedded in the e-book. This aligns with Mayer's cognitive theory of multimedia learning and the theory of self-determination (Deci & Ryan, 1985).

Overall, the study affirms the pedagogical feasibility and practical effectiveness of the FEPLM in supporting 21st-century learning goals across diverse educational settings.

5. Conclusion and Suggestions

5.1 Conclusion

This study developed and tested a web-based physics e-book designed around a Problem-Based Learning (PBL) framework to improve students' critical thinking and learning independence. Conducted in a multicultural senior high school environment in Indonesia, the study confirmed the product's pedagogical feasibility and statistical effectiveness. Key conclusions are as follows:

1. The Flipbook E-book Physics Learning Media (FEPLM) was validated by experts as a highly feasible learning tool in terms of content, media, and usability.
2. The implementation of FEPLM significantly improved students' critical thinking skills, as evidenced by a large effect size in GLM analysis.
3. Learning independence also increased substantially among students in the experimental class, confirming the value of integrating PBL within digital learning resources.
4. The design effectively accommodated students' diverse cultural backgrounds, offering a flexible and engaging learning experience across platforms.

5.2 Educational Implications

The study offers important implications for educators, instructional designers, and policymakers:

- Web-based e-books grounded in PBL are effective for teaching complex physics topics such as static fluids.
- Interactive digital media can address challenges of differentiation in multicultural classrooms by providing scaffolded, self-paced learning experiences.
- Embedding critical thinking and self-regulated learning frameworks into curriculum design enhances 21st-century competencies.

5.3 Suggestions for Future Research and Development

While the results are promising, several areas remain for further exploration:

- Longitudinal studies are needed to examine the sustained impact of FEPLM on student performance and attitudes.
- Further development can integrate Artificial Intelligence features for adaptive feedback based on student performance.
- Future research should also explore teacher training strategies to optimize the use of PBL-based digital learning tools.
- The platform may be adapted for other physics topics or extended to interdisciplinary STEM education.

The FEPLM represents a scalable and inclusive solution to modern educational challenges and offers a foundation for future innovations in digital pedagogy.

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