Vol. 4, No. 3, September 2026, pp. 1460-1474
INTERNATIONAL JOURNAL OF
POST AXIAL
FUTURISTIC TEACHING AND LEARNING
https://journal.amorfati.id/index.php/postaxial | | ISSN 3025-7549

Development of Digital Teaching Materials Integrating Ethnophysics and PBL on Fluids to Enhance Students' Critical Thinking

Adrini Yulita [1,a], Festiyed [2,a], Asrizal [3,a], Fatmi Mufid [4,a], Fuja Novira [5,a]
[1,2,3,4,5] Padang State University, Indonesia
adriniyulita37@guru.sma.belajar.id [a]

Article History:
Received:
24-07-2026
Revised:
22-08-2026
Accepted:
13-09-2026

Keywords:
Critical thinking; Digital teaching materials; Ethnophysics; Fluids; Problem-Based Learning

***Correspondence Address:**
*Corresponding author:
adriniyulita@gmail.com

Abstract:
Critical thinking is a central competency in physics learning, yet preliminary evidence in this study showed that students' skills remained low while digital teaching materials, local cultural contexts, and structured problem-based learning were not optimally integrated. This study aimed to develop digital teaching materials integrating ethnophysics and Problem-Based Learning (PBL) on fluid topics and to evaluate their validity, practicality, and effectiveness. The study employed Research and Development using the ADDIE model. Three expert validators assessed the product, with validity analyzed using Aiken's V. Practicality was evaluated through student and teacher response questionnaires, while effectiveness was examined using pretest-posttest data from experimental and control classes through N-Gain analysis, the Mann-Whitney test, and effect-size analysis. The developed materials integrate fluid concepts with West Sumatran cultural phenomena and include learning materials, worksheets, videos, simulations, exercises, evaluation, and reflection activities. The mean Aiken's V value was 0.78, indicating that the materials met the validity criterion. Student practicality reached 93.92%, corresponding to the very practical category, while all indicators assessed by teachers were also categorized as very practical. The experimental class achieved a critical-thinking N-Gain of 0.613, categorized as moderate, compared with 0.085 in the control class, categorized as low. The Mann-Whitney test showed a significant difference in posttest scores between the two classes ($p < 0.001$), accompanied by a very large effect size ($r = 0.859$). Based on these validation, practicality, and effectiveness indicators, the developed digital teaching materials met the criteria for validity and high practicality and demonstrated effectiveness in improving students' critical thinking on fluid topics within contextual physics learning.

Introduction (مقدمة)

Critical thinking is a core 21st-century competence because physics learning requires students not only to recall formulas but also to interpret evidence, construct explanations, evaluate alternatives, draw justified conclusions, and determine appropriate strategies for solving problems. Ennis (2011) conceptualizes critical thinking through abilities that include elementary clarification, basic support, inference, advanced clarification, and strategy and tactics. These abilities are particularly relevant to fluid mechanics, where students must connect mathematical relationships with observable phenomena such as pressure, buoyancy, flow continuity, and changes in fluid velocity. Therefore, physics learning on fluid topics needs to provide students with opportunities to analyze phenomena, examine evidence, construct explanations, and justify solutions rather than merely apply mathematical formulas.

The preliminary phase of this study identified a gap between these expectations and classroom practice. Students' initial critical-thinking performance was still limited, while the learning resources used in class were dominated by conventional textbooks. Teacher interviews also indicated that digital media were not used consistently because preparing separate presentations, videos, simulations, and supporting resources required additional time and depended on available facilities. Students reported a need for more varied learning resources and expressed interest in digital materials containing visualizations, videos, simulations, and contexts related to everyday life. Thus, the instructional problem was not merely a lack of information or digital media, but the absence of a coherent learning resource that could organize conceptual content, contextual problems, investigation, reasoning, evaluation, and reflection within a single learning sequence.

Digital teaching materials offer one possible response to this problem when they do more than transfer printed text to a digital screen. Their instructional value lies in their ability to organize multiple representations and learning activities so that students can move between explanation, visualization, investigation, practice, and reflection. Research on interactive physics e-modules has shown that digitally structured learning resources can support active learning when their content, activities, and interface are aligned with the intended learning model (Arifin et al., 2024; Kannan et al., 2022). Practicality is also an important consideration because teaching materials that are conceptually appropriate but difficult for teachers or students to use are unlikely to be implemented consistently in classroom learning (Dewi et al., 2023; Atwa et al., 2024). Therefore, digital teaching materials need to be designed not only as repositories of content but also as structured environments that support students' learning processes.

Contextualization through ethnophysics provides a second design principle. In this study, fluid concepts are connected with local phenomena and technologies found in West Sumatra, including water wheels (kincir air), tabek, traditional fish traps (lukah), and traditional coconut-milk presses (kacik). These contexts allow scientific concepts to be approached through objects and practices that are familiar and meaningful to students. Culturally relevant science pedagogy emphasizes that stronger connections between formal scientific knowledge and students' lived experiences can be established when local knowledge is treated as a meaningful instructional context rather than merely as an ornamental example (Smith et al., 2022). Empirical studies have also indicated that ethnoscience and local-wisdom contexts can support critical thinking when they are integrated with problem-centered learning activities (Gummah et al., 2023; Safitri et al., 2024). In this sense, ethnophysics provides a contextual bridge through which students can relate abstract physics concepts to phenomena found in their own cultural environment.

The third design principle is Problem-Based Learning (PBL). PBL organizes learning around meaningful problems that require students to identify what is known, determine what needs to be investigated, analyze relevant information, evaluate possible explanations, and propose reasoned solutions. This orientation is consistent with the constructivist rationale of PBL described by Arends (2012) and Savery (2006). More recent syntheses and empirical studies indicate that PBL can strengthen critical thinking when the problems presented are sufficiently authentic and the instructional sequence provides appropriate guidance for inquiry and reasoning (Hafizah et al., 2024; Yu & Zin, 2023). Therefore, the potential contribution of PBL to critical thinking depends not only on the use of problems but also on the quality of those problems, the sequence of learning activities, and the resources available to students during the inquiry process.

The existing studies provide important foundations for the present research, but they also reveal a more specific instructional gap. Research on digital teaching materials has emphasized the role of structured and interactive resources in supporting learning (Arifin et al., 2024; Kannan et al., 2022), while studies on ethnoscience and local wisdom have demonstrated the potential of culturally familiar contexts to support critical thinking (Gummah et al., 2023; Safitri et al., 2024). Studies on PBL have likewise shown its potential to promote critical-thinking processes through authentic and structured problem solving (Hafizah et al., 2024; Yu & Zin, 2023). However, these elements are generally emphasized in partial combinations. A more specific need remains for digital physics teaching materials that systematically integrate local ethnophysics contexts, PBL syntax, and explicit critical-thinking indicators within one coherent learning architecture, particularly for static and dynamic fluid topics.

This gap is important because simply providing digital content does not necessarily ensure contextual or critical-thinking-oriented learning. Similarly, presenting local cultural phenomena without embedding them in a structured problem-solving process may only function as contextual illustration, while implementing PBL without appropriate digital resources may limit the representations and learning support available to students. Therefore, the instructional challenge addressed in this study concerns how these components can be deliberately connected: digital materials provide the learning environment, ethnophysics supplies meaningful contextual phenomena, PBL organizes the problem-solving process, and critical-thinking indicators define the reasoning abilities expected from students. The integration of these components is intended to create a learning sequence in which technology, cultural context, problem solving, and reasoning support one another rather than operate as separate instructional elements.

At the product level, the instructional scope covers both static and dynamic fluid concepts, including hydrostatic pressure, Pascal's law, Archimedes' principle, discharge, continuity, and Bernoulli-related relationships. Local culture is not treated as a separate enrichment topic. Instead, local phenomena are embedded within learning problems so that students are required to use physics concepts to interpret observations, identify relevant information, compare explanations, analyze relationships among variables, draw conclusions, and justify possible solutions. These activities are aligned with the five critical-thinking dimensions adopted in this study: elementary clarification, basic support, inference, advanced clarification, and strategy and tactics (Ennis, 2011).

Accordingly, the novelty of this study lies not in the individual use of digital teaching materials, ethnophysics, PBL, or critical-thinking activities, since these components have been addressed in previous research. Rather, the novelty lies in their systematic integration within a single digital teaching material specifically designed for fluid learning. The developed product integrates West Sumatran ethnophysics contexts with PBL syntax and explicitly aligns learning activities with critical-thinking indicators. In addition, the product is evaluated comprehensively through expert validation, teacher and student practicality assessments, and a controlled pretest-posttest effectiveness test. This evaluation allows the study to examine not only whether the product is appropriate in terms of content and design, but also whether it is practical for classroom use and effective in supporting measurable changes in students' critical-thinking performance.

Based on this research gap, this study aimed to determine (1) the validity, (2) the practicality, and (3) the effectiveness of digital teaching materials integrating ethnophysics and Problem-Based Learning on fluid topics for improving high-school students' critical-thinking skills.

▣ Method (منهج)

This study used Research and Development (R&D) with the ADDIE development model, consisting of Analysis, Design, Development, Implementation, and Evaluation. The model was used as an iterative development sequence rather than as five isolated activities: evaluation and revision were conducted between stages to reduce design errors before field implementation. Figure 1 summarizes the procedure actually implemented in the thesis.

Figure 1. ADDIE procedure used to develop and evaluate the ethnophysics-PBL digital teaching materials.

Development Stages and Evidence

The ADDIE procedure was operationalized through distinct development decisions and evidence sources. Table 1 summarizes what was examined, what evidence was collected, and what output was produced at each stage. This matrix makes explicit that the product was progressively specified, validated, revised, implemented, and evaluated rather than produced in a single design step.

Table 1. ADDIE stages, evidence sources, and development outputs.

ADDIE stage	Main activities in this study	Evidence/source	Stage output
Analysis	Curriculum and fluid-content analysis; learner characteristics; media use; baseline critical thinking	Phase F curriculum; 32 Grade XI student questionnaire; teacher interviews from two schools; 15-item essay test	Product requirements and learning needs
Design	Organize static/dynamic fluid content; select ethnophysics contexts; map PBL syntax to critical-thinking tasks	Curriculum indicators, contextual phenomena, PBL and critical-thinking framework	Initial product structure and learning sequence
Development	Produce digital material; expert review; revise content, visuals, interactivity, and learning components	Three expert validators; Aiken's V; validator comments	Validated and revised digital teaching material
Implementation	Use the product in the experimental class; collect user responses; administer pretest and posttest	Two Phase F classes (N = 64 for effectiveness analysis); student and teacher practicality questionnaires	Practicality and effectiveness evidence
Evaluation	Review implementation results and feedback; establish the final evaluated version	Validation, practicality, field-test outcomes, and revision record	Final product and study conclusions

The thesis conceptual framework connects product planning, PBL-based implementation, and assessment to the intended development of critical thinking. Figure 2 reproduces that framework because it clarifies how the digital material functions as the organizing medium linking the cultural context, the learning process, and the assessment of thinking skills.

Figure 2. Conceptual framework of the ethnophysics-integrated problem-based digital material (adapted from the thesis conceptual framework).

Research Context and Participants

The needs-analysis stage included a student-characteristics questionnaire administered to 32 Grade XI students and interviews with physics teachers from two schools in Padang to identify media use, learning constraints, and desired digital-resource characteristics. The main field research was conducted at SMA Pembangunan Laboratorium UNP, Padang, West Sumatra, from 15 April to 10 August 2026. Two Phase F classes served as the experimental and control groups. The effectiveness analysis involved a total of N = 64 students, as reported in the effect-size analysis. The experimental class learned with the developed ethnophysics-integrated PBL digital materials, whereas the control class used conventional student learning materials.

Three expert validators representing physics/material content, learning media, and instruction evaluated the product before implementation. Validation was followed by revision, after which practicality was assessed by students and the physics teacher who used the material. The study therefore involved three evidence sources for product quality: expert judgment, user responses, and students' critical-thinking outcomes.

Product Design and Development

During Analysis, the researcher examined curriculum requirements for Phase F Grade XI physics, the fluid topic, student characteristics, current media use, and baseline critical-thinking skills. The initial assessment of critical thinking used 15 essay questions covering five Ennis-oriented indicators: elementary clarification, basic support, inference, advanced clarification, and strategy and tactics. Curriculum and needs evidence were then translated into product specifications.

During Design, the fluid content was organized around contextual phenomena, PBL activity sequences, and critical-thinking tasks. The product integrated local ethnophysics contexts with learning materials, student worksheets, videos, simulations, exercises, evaluations, and reflection. During Development, the digital teaching material was produced, reviewed by experts, and revised according to validator comments. Reported revisions included adjustments to color composition and product title, addition of student worksheets, clearer PBL syntax and indicators, improvements to summaries and observation tables, interactive quizzes, video and link presentation, usage instructions, and motivational statements. The revised product proceeded to implementation after it met the required validity criteria.

Alignment of PBL, Critical Thinking, and Ethnophysics

A central design feature of the thesis is the explicit alignment of the five PBL phases with the five critical-thinking dimensions and contextual ethnophysics questions. Table 2 condenses the original alignment table by retaining the PBL phase, the targeted thinking dimension, representative indicators, and one representative water-wheel problem from the thesis.

Table 2. Alignment of PBL phases, critical-thinking dimensions, and contextual ethnophysics prompts.

PBL phase	Critical-thinking dimension	Representative indicators	Representative contextual prompt from the thesis
Problem orientation	Basic clarification	Focus questions; analyze arguments; ask/answer clarification questions	Why can a traditional water wheel rotate faster when water discharge increases? Analyze the phenomenon using dynamic-fluid concepts.
Organize students	Basic support	Evaluate source credibility; consider observations; use relevant information	Compare information from the local community and a physics textbook about water flow on a water wheel. Which source is more reliable? Explain.
Guide investigation	Inference	Draw deductive/inductive conclusions; make decisions; evaluate conclusions	If the cross-sectional area of the water flow is reduced, how will flow velocity and water-wheel rotation change? Explain.
Develop and present results	Advanced clarification	Define terms; identify assumptions; clarify meaning; relate concepts	Analyze the relationship among discharge, pressure, and flow velocity in the context of a water wheel.
Analyze and evaluate	Strategy and tactics	Determine actions; choose problem-solving strategy; collaborate; evaluate decisions	Evaluate whether the water-wheel design is effective based on the experimental results.

Instruments and Data Analysis

Validity was assessed using expert-rating instruments covering material substance, instructional design, visual communication, software utilization, the PBL model, ethnophysics integration, critical-thinking support, and language. Expert ratings were summarized using Aiken's

V (Aiken, 1985). Practicality questionnaires for students and teachers addressed usability, ease of use, attractiveness, clarity, efficiency, and/or cost saving as represented in the thesis instruments. Percentages were interpreted using the categories established in the thesis.

Effectiveness was assessed with pretest and posttest critical-thinking scores in the experimental and control classes. Initial equivalence was checked using descriptive statistics, Kolmogorov-Smirnov normality tests, Levene's homogeneity test, and an independent-samples t-test. Relative improvement was calculated using normalized gain (N-Gain) following the approach used in the thesis (Hake, 1998). For the posttest comparison, the experimental data met normality whereas the control data did not; therefore, the group difference was tested with Mann-Whitney U. The magnitude of the difference was then expressed as effect-size r calculated from Z and total sample size. Statistical decisions used a 0.05 significance level.

▤ Result (نتائج)

1. Analysis and Product Development

The analysis stage confirmed the need for a digital resource that was systematic, flexible, and able to combine several instructional components in one medium. Interviews showed that videos and PowerPoint had been used, but their use depended on preparation time and available facilities. Student-characteristics data also supported the use of digital learning and contextual examples. These findings led to a design in which fluid concepts were presented through local phenomena and then connected to PBL activities that required students to identify problems, investigate information, interpret data, and formulate solutions.

Needs-Analysis Evidence

The need for the product was supported by multiple sources rather than by a single classroom observation. The curriculum analysis defined the required fluid competencies, the learner questionnaire described students' preferred characteristics of learning resources, teacher interviews identified practical media constraints, and the baseline essay test documented critical-thinking performance. Table 3 summarizes these inputs and their direct design implications.

Table 3. Needs-analysis evidence used to define the digital teaching-material requirements.

Analysis aspect	Evidence source	Key finding retained from the thesis	Design implication
Curriculum and content	Phase F Grade XI physics curriculum	Fluid learning requires conceptual understanding, application, investigation, evaluation of solutions, and communication of results.	Include static and dynamic fluid content with investigation and problem-solving activities.
Learner characteristics	Questionnaire to 32 Grade XI students	Students needed more varied learning resources and showed interest in digital materials with visualizations, video, simulation, and everyday contexts.	Use a flexible digital format with multimodal components and contextual examples.
Existing media use	Physics-teacher interviews at two schools in Padang	Video and PowerPoint had been used, but preparation time and limited supporting facilities constrained consistent use.	Integrate material, media, activities, and evaluation in one structured resource.
Baseline critical thinking	15 essay items covering five Ennis-oriented dimensions	Overall means were 65.04 (control) and 65.41 (experimental), indicating room for improvement; baseline difference was nonsignificant.	Embed explicit critical-thinking tasks across the PBL sequence and evaluate effectiveness with comparable groups.

The indicator-level baseline pattern also shows that the need for improvement was not concentrated in only one dimension. Table 4 reproduces the thesis means for the five critical-thinking indicators before the intervention. The lowest mean in the control class occurred in basic clarification (55.90), whereas the lowest mean in the experimental class occurred in advanced clarification (58.18). Strategy and tactics was identical in both classes (66.41).

Table 4. Baseline critical-thinking means by indicator.

Code	Critical-thinking indicator	Control	Experimental
CT1	Basic clarification / providing a simple explanation	55.90	63.54
CT2	Basic support / building basic skills	66.88	67.03
CT3	Inference / drawing conclusions	66.22	71.88
CT4	Advanced clarification / providing further explanation	69.79	58.18

Code	Critical-thinking indicator	Control	Experimental
CT5	Strategy and tactics	66.41	66.41
Mean	Overall critical-thinking score	65.04	65.41

The final product combined materials on static and dynamic fluids with ethnophysics phenomena, student worksheets, learning videos, simulations, interactive exercises, evaluation, and reflection. Validator feedback did not require a change in the research focus or the core product concept; rather, it improved instructional completeness, visual organization, interactivity, and explicit alignment between PBL syntax and critical-thinking indicators. After these revisions, the product was subjected to formal validity evaluation.

The product documentation in the thesis confirms that these components were implemented as an integrated digital resource rather than described only as design intentions. Figure 3 shows the developed home page and navigation structure, in which material, static-fluid and dynamic-fluid sections, video, evaluation, and other learning components are accessible from the same product environment.

Figure 3. Developed digital teaching-material interface and navigation reproduced from the thesis product documentation.

The PBL layer is visible in the learning activity itself. As illustrated in Figure 4, students are presented with a contextual water-wheel problem and are explicitly directed to identify the problem and provide a simple explanation, linking the first PBL phase to the targeted critical-thinking dimension.

Figure 4. Example of a contextual PBL activity targeting basic clarification in the developed material.

Table 5. Expert validation results for the developed digital teaching materials.

Validity component	Aiken's V	Category
Material substance	0.84	Very valid
Instructional design	0.79	Valid
Visual communication display	0.72	Valid
Software utilization	0.75	Valid
Problem-Based Learning model	0.80	Valid
Ethnophysics integration	0.83	Very valid
Critical-thinking skills	0.75	Valid
Language	0.77	Valid
Mean	0.78	Valid

Table 5 shows that every evaluated component reached at least the valid category. Material substance (V = 0.84) and ethnophysics integration (V = 0.83) were classified as very valid, while the overall mean was V = 0.78. The result indicates that the product was sufficiently aligned in content, instructional design, PBL structure, ethnophysics context, critical-thinking support, language, and digital presentation to proceed to implementation after the required revisions.

The overall validity score should be read together with the revision process. Expert judgment was used formatively, and the thesis records specific changes made before field implementation. Table 6 summarizes the principal revisions without adding changes beyond those documented in the thesis.

Table 6. Principal validator-driven revisions before implementation.

Revision area	Validator feedback/identified need	Revision incorporated in the product
Visual organization	Color composition required alignment and refinement.	Color composition was adjusted and made more consistent.
Product identity	The product title required adjustment.	The product title was revised.
Learning completeness	Student worksheets and clearer PBL syntax/indicators were needed.	Worksheets were added and PBL syntax/indicators were clarified.
Content support	Summaries and observation tables required improvement.	The summary and observation-table presentation were refined.
Interactivity	Interactive assessment needed strengthening.	An interactive quiz was added.
Media and links	Video and link presentation required improvement.	Video and link presentation was improved.
User guidance	Usage directions and learner motivation needed reinforcement.	Usage instructions and motivational statements were added.

2. Practicality

Student responses produced an overall practicality score of 93.92%, categorized as very practical. The highest student indicator was cost saving (95.74%), while the lowest was usability (92.47%); all student indicators nevertheless exceeded 90%. Teacher evaluation likewise placed every reported indicator in the very practical category, as summarized in Table 7.

Table 7. Practicality results from student and teacher assessments.

Assessment/indicator	Percentage (%)	Category
Students - overall	93.92	Very practical
Students - usable	92.47	Very practical
Students - ease of use	93.06	Very practical
Students - attractiveness	95.29	Very practical
Students - clarity	93.24	Very practical
Students - cost saving	95.74	Very practical
Teacher - usable	98.67	Very practical
Teacher - ease of use	97.33	Very practical
Teacher - attractiveness	98.67	Very practical
Teacher - clarity	97.78	Very practical
Teacher - efficiency	98.33	Very practical
Teacher - cost saving	97.33	Very practical

The convergence of student and teacher assessments indicates that the product was not merely acceptable to experts but operable in classroom use. Students perceived the digital material as easy to use, attractive, clear, and economical, while the teacher judged it highly usable across all reported indicators. No implementation-stage user feedback required changes to the product's core components, so the evaluated version was established as the final product after the implementation and evaluation stages.

The student-indicator profile is shown graphically in Figure 5. All five student indicators were above 92%, with attractiveness (95.29%) and cost saving (95.74%) receiving the highest ratings. This spread supports the overall 93.92% result and shows that the very-practical classification was not produced by a single exceptionally high indicator.

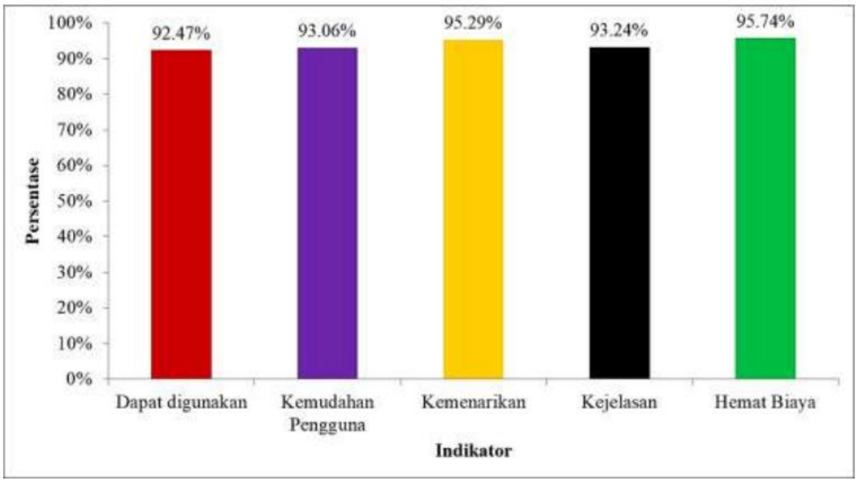

Figure 5. Student practicality results by indicator, reproduced from the thesis analysis.

3. Effectiveness for Critical Thinking

Before the intervention, the two classes showed highly similar critical-thinking performance. The control-class mean was 65.04 and the experimental-class mean was 65.41. Both initial distributions met the normality criterion, the variances were homogeneous, and the independent-samples t-test showed no significant baseline difference, $t(62) = 0.382$, $p = 0.704$. This baseline equivalence supports interpretation of the subsequent group differences in relation to the implemented learning conditions.

Table 8. Baseline critical-thinking statistics and equivalence tests.

Parameter	Control	Experimental
Mean	65.04	65.41
Standard deviation	3.90	3.84

Parameter	Control	Experimental
Median	65.92	65.95
Maximum	71.06	74.65
Minimum	57.92	56.68
Kolmogorov-Smirnov p	0.095	0.200
Levene homogeneity p	0.622	0.622
Independent t-test	t = 0.382; df = 62; p = 0.704	t = 0.382; df = 62; p = 0.704

After implementation, the experimental class achieved a mean posttest score of 86.63 compared with 68.00 in the control class. Relative improvement also differed markedly: the experimental N-Gain was 0.613 (moderate), whereas the control N-Gain was 0.085 (low). Table 10 summarizes the pretest, posttest, and gain values without altering the thesis data.

The posttest distributions provide additional descriptive context for the mean difference. Table 9 retains the complete descriptive statistics reported in the thesis. The experimental class not only had the higher mean but also a substantially higher minimum score (78.76 versus 59.84), while the standard deviations remained similar between groups.

Table 9. Posttest descriptive statistics for critical-thinking skills.

Statistic	Control	Experimental
Mean	68.00	86.63
Standard deviation	3.67	3.75
Median	69.24	86.80
Variance	13.44	14.06
Maximum	72.81	93.19
Minimum	59.84	78.76
Range	12.97	14.43

Table 10. Pretest, posttest, and N-Gain results for critical-thinking skills.

Class	Pretest	Posttest	N-Gain	Category
Control	65.04	68.00	0.085	Low
Experimental	65.41	86.63	0.613	Moderate

The posttest normality test produced $p = 0.200$ for the experimental class and $p = 0.023$ for the control class. Because one group did not meet the normality assumption, the thesis used the Mann-Whitney test rather than a parametric between-group comparison. The test reported $U = 0.000$, $Z = -6.875$, and $p = 0.000$ (reported conventionally as $p < 0.001$). The corresponding effect-size r was 0.859, categorized as very large. Thus, the between-group difference was not only statistically significant but also substantial in magnitude.

Figure 6 visualizes the class mean scores before and after instruction. The graph is descriptive and uses only the thesis means; inferential interpretation remains based on the Mann-Whitney and effect-size results reported below.

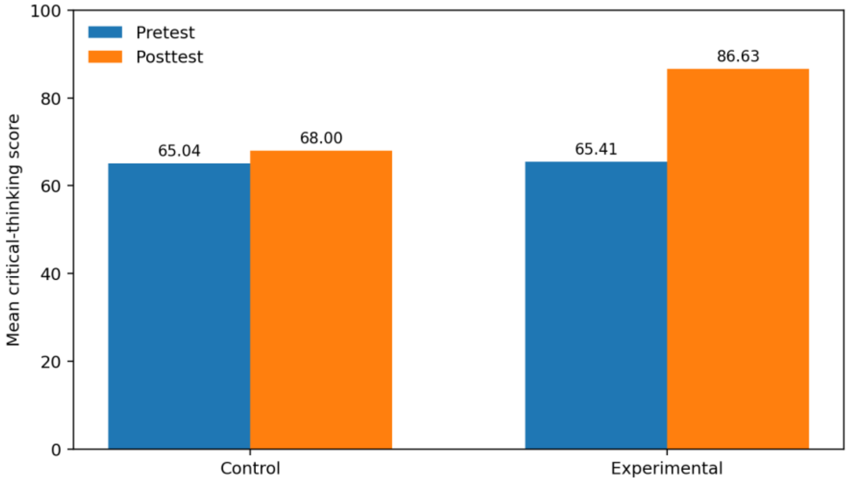

Figure 6. Mean pretest and posttest critical-thinking scores in the control and experimental classes.

Table 11. Posttest difference and effect-size analysis.

Parameter	Value	Interpretation
Kolmogorov-Smirnov p - experimental	0.200	Normal
Kolmogorov-Smirnov p - control	0.023	Not normal
Levene's test p	0.875	Homogeneous
Mann-Whitney U	0.000	Reported in thesis
Z	-6.875	-
Sig. (2-tailed)	0.000	p < 0.001
Effect size r	0.859	Very large

◆ Discussion (مناقشة)

Validity and Alignment of the Developed Product

The validation results show that the product achieved an acceptable degree of coherence across content, pedagogy, cultural context, critical-thinking indicators, and digital presentation. This point is important because an integrated teaching material can fail even when each separate component is sound: the content may be correct while the learning model is not visible, or the digital interface may be attractive while activities do not operationalize the intended cognitive skills. The mean Aiken's V of 0.78 indicates that the final design achieved sufficient alignment for implementation, and the strongest ratings for material substance and ethnophysics integration confirm that the core conceptual and contextual elements were recognized by the validators.

The variation among validity components is informative for interpreting product quality. Material substance ($V = 0.84$) and ethnophysics integration ($V = 0.83$) were the strongest components, while visual communication was lower ($V = 0.72$) but still valid. At the indicator level reported in the thesis, visual navigation, typography, and layout each obtained $V = 0.67$, whereas the media indicator obtained $V = 0.83$. The pattern supports the role of expert validation as a diagnostic step: the conceptual core of the material was strong, while several presentation and interface elements required refinement before implementation.

The revision process also explains why validation should be understood as formative rather than ceremonial. The validators' recommendations led to concrete changes in worksheets, PBL syntax, indicators, summaries, interactive quizzes, observation tables, videos and links, and user guidance. Similar development studies emphasize that iterative expert feedback is central to turning a draft e-module into an instructional resource whose content, interface, and learning sequence function as one system (Rohmatin et al., 2022; Sajidan et al., 2025). Schaller et al. (2023) likewise demonstrates that problem-centered learning is most productive when critical-thinking demands are made explicit rather than assumed to emerge automatically.

Practicality as a Condition for Classroom Use

High practicality from both students and the teacher indicates that the material was feasible within the actual classroom conditions of the study. The student mean of 93.92% is particularly relevant because a digital resource can only support inquiry if learners can navigate it without excessive operational burden. The teacher's ratings, all above 97%, reinforce the same conclusion from the instructional side. These results are compatible with research showing that structured digital modules can improve usability by consolidating learning resources and clarifying the sequence of student activity (Dewi et al., 2023; Nurdyansyah et al., 2024).

The indicator-level results strengthen this interpretation. Student ratings ranged only from 92.47% to 95.74%, and teacher ratings ranged from 97.33% to 98.67%. Thus, the classroom-use judgment was consistently positive across usability, ease of use, attractiveness, clarity, efficiency, and cost saving rather than being driven by one dimension. In practical terms, this consistency matters because the product requires students to move among material, contextual problems, worksheets, video, simulation, quizzes, and reflection; weak navigation or unclear instructions would have interrupted the PBL process even if the academic content were valid.

The product design may account for this practicality. Rather than requiring students to switch between disconnected resources, it placed materials, contextual phenomena, worksheets, video, simulation, practice, evaluation, and reflection within one digital learning structure. The local context can also reduce the conceptual distance between a physics problem and students' existing experience. Atwa et al. (2024) notes that the perceived quality of PBL learning is strongly shaped by the organization of the tutorial experience; in this study, the digital material functioned as an organizing scaffold for that experience.

Effectiveness and the Development of Critical Thinking

The main effectiveness finding is the divergence between two initially comparable classes. Before the intervention, the mean scores differed by only 0.37 points and the baseline t-test was nonsignificant. After instruction, the experimental mean reached 86.63 while the control mean was 68.00. The experimental N-Gain of 0.613 was moderate rather than high, so the result should not be overstated; however, it was substantially higher than the control N-Gain of 0.085. The posttest Mann-Whitney result and the very large effect size ($r = 0.859$) provide convergent evidence that the learning condition using the developed material was associated with much stronger critical-thinking performance.

The baseline indicator profile also helps explain why an explicitly structured critical-thinking design was appropriate. The control class was weakest on basic clarification (55.90), while the experimental class was weakest on advanced clarification (58.18); inference was comparatively stronger in the experimental group (71.88). The material therefore did not target a single generic notion of higher-order thinking. Its activities were mapped across clarification, evidential support, inference, further explanation, and strategic decision making, allowing PBL tasks to provide repeated opportunities to practice different forms of reasoning.

This pattern is theoretically consistent with PBL because critical thinking is practiced through the sequence of problem identification, information gathering, analysis, and solution justification rather than through explanation alone. Meta-analytic evidence has repeatedly linked PBL with gains in critical-thinking and problem-solving outcomes (Manuaba et al., 2022; Hafizah et al., 2024). Physics-specific studies also report improved critical thinking when e-modules and flipped or problem-based learning structures require students to engage actively with problems and evidence (Kristiantari et al., 2023; Sutrio et al., 2023). Yu and Zin (2023) further emphasize that adaptations of PBL oriented explicitly toward critical thinking are more defensible than assuming that any problem task will automatically produce higher-order thinking.

The digital and cultural components likely supported this mechanism in complementary ways. Digital features provided multimodal access to explanations, video, simulation, and tasks, while ethnophysics supplied authentic contexts for reasoning. Gummah et al. (2023) found that ethnoscience-integrated PBL can enhance critical thinking, and Safitri et al. (2024) similarly positioned local-wisdom PBL worksheets as instruments for training critical reasoning. From a culturally responsive perspective, local phenomena can help students connect abstract scientific models with familiar practices, supporting the transition from everyday observation to scientific explanation (Smith et al., 2022). The present material used this connection on fluid mechanics, where phenomena such as water wheels, traditional traps, reservoirs, and mechanical presses can be interpreted through pressure, buoyancy, continuity, and flow principles.

The effect magnitude is also consistent with studies in which interactive or problem-based digital modules created sustained opportunities for students to analyze information and make decisions rather than passively receive content (Hamidah et al., 2024; Kannan et al., 2022). Nevertheless, the current result should be interpreted within its design boundaries. The study establishes effectiveness for the tested material, participants, duration, and critical-thinking outcome; it does not establish that every ethnophysics-PBL digital material will produce the same effect or that the effect will persist long term.

Contribution, Novelty, and Implications

The contribution of this study lies in the deliberate integration of three instructional layers into a single product: a digital resource architecture, PBL as the learning process, and West Sumatran ethnophysics as the contextual knowledge environment. The novelty is therefore not a new statistical method or a new theory of critical thinking. It is the development and empirical evaluation of an integrated design in which fluid concepts, local phenomena, PBL syntax, and critical-thinking indicators are made operational within one digital teaching material. This integration extends prior work on local-wisdom modules and ethnoscience-PBL designs (Wati et al., 2024; Fitria et al., 2024; Saddia et al., 2025).

This integration is especially visible in the water-wheel sequence retained from the thesis. Students begin by clarifying why rotation changes with water discharge, compare local and textbook explanations, infer the consequences of changes in cross-sectional area, connect discharge-pressure-velocity concepts, and finally evaluate the effectiveness of a proposed design. The cultural phenomenon therefore functions as the object of scientific analysis throughout the learning cycle. That design choice distinguishes substantive ethnophysics integration from simply placing a local-culture photograph beside conventional explanatory text.

Boundary Conditions and Research Limitations

The evidence should nevertheless be interpreted within the boundaries documented in the thesis. The field test involved only two Phase F classes; the content was limited to static and dynamic fluids; the ethnophysics contexts were drawn from West Sumatra; and the implementation period was relatively short. Because the product is digital, access also depends on suitable devices and adequate internet connectivity. Finally, effectiveness was operationalized through pretest-posttest critical-thinking performance, and the experimental N-Gain was moderate (0.613), not high. These limitations do not negate the significant group difference or the very large effect size, but they constrain generalization to other schools, topics, cultural contexts, and longer-term learning outcomes.

Practically, the findings support the use of the material as an alternative source for contextual fluid instruction, provided that devices and internet access are adequate. Teachers can adapt the selected ethnophysics phenomena and PBL problems to their own students and environments without changing the pedagogical principle: the cultural context should function as a problem and evidence source, not merely as a decorative example. At the same time, the moderate N-Gain suggests room to strengthen the duration, scaffolding, and repeated critical-thinking practice in future versions.

✓ Conclusion (خاتمة)

The digital teaching materials integrating ethnophysics and Problem-Based Learning on fluid topics met the validity, practicality, and effectiveness criteria examined in this study. The product achieved a mean Aiken's V of 0.78, indicating valid quality, while student practicality reached 93.92% and all teacher-rated indicators were categorized as very practical. Effectiveness testing showed that the experimental class achieved a moderate N-Gain of 0.613, compared with 0.085 in the control class, with a significant posttest difference ($p < 0.001$) and a very large effect size ($r = 0.859$). These findings indicate that the developed materials were valid, highly practical, and effective in supporting students' critical thinking within the conditions of the field test.

Practically, the developed materials provide teachers with an integrated digital resource that combines fluid concepts, West Sumatran ethnophysics contexts, PBL activities, simulations, exercises, and critical-thinking tasks within a single learning sequence, reducing the need to prepare separate learning resources. The materials can therefore serve as an alternative resource for contextual physics instruction, particularly for fluid topics. Future studies should examine their use with broader populations, longer implementation periods, other physics topics, and more diverse cultural contexts.

◇ Acknowledgment (شكر وتقدير)

The author acknowledges Prof. Dr. Festiyed, M.Si. for academic supervision; the expert validators Dr. Fatni Mufit, S.Pd., M.Si., Dr. Leni Aziyus Fitri, S.Pd., M.Si., and Dr. Emiliannur, M.Pd.; and the school leaders, physics teachers, and students who supported the study and its implementation. The author also acknowledges the Master of Physics Education Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang.

Conflict of interest: The author declares no conflict of interest.

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