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Development of Ethnoscience-Based Physics Teaching Materials on the Topic of Motion Dynamics to Enhance Students' Critical Thinking Skills

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Abstract

This study developed and tested the effectiveness of ethnoscience-based physics teaching materials on the topic of motion dynamics to enhance students' critical thinking skills. A Research & Development approach using the ADDIE model (Analyze, Design, Develop, Implement, Evaluate) was employed. In the Analyze phase, surveys and interviews identified that over 70% of students struggled to understand the concepts of force and acceleration and that the existing materials lacked local contextual relevance. The Design phase produced a framework that integrated the theory of motion dynamics with the Cidomo phenomenon, experimental worksheets, reflective questions, and a critical thinking assessment rubric. All components were produced and validated by two experts in physics ethnoscience, yielding an average S-CVI score of 86% (rating "Highly Feasible") and strong internal reliability (Cronbach's α = 0.88). During the Implement phase, 95% of students actively conducted field experiments, 80% posed critical questions, and 70% were able to justify their results based on physics theory. Formative and summative evaluations showed that the average pre-test score increased from 17.75 to 78.75 in the post-test ($p < 0.001$; Cohen's d = 5.50). All students achieved a high n-gain category (average g = 0.84). Qualitative data supported the quantitative findings, revealing themes of "Increased Self-Confidence," "Deep Critical Reflection," and "Relevance of Local Context." These results confirm that integrating local cultural context through ethnoscience-based physics teaching materials significantly facilitates the enhancement of students' critical thinking skills in motion dynamics.

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INTRODUCTION

Education serves as the foundation of national development by providing individuals with the knowledge, skills, and values necessary to contribute effectively to society. In an era of globalization and rapid technological advancement, demands for critical thinking, creativity, and adaptability have intensified so that students can navigate the complexities of a changing world (Jin, 2023; Kivunja, 2015). Within the context of physics instruction, critical thinking is essential for students to evaluate information rationally and make sound decisions based on their understanding of physics concepts (Rutto et al., 2023; Musyarrof et al., 2018). Contextualized, active learning has been shown to enhance students' critical thinking skills by facilitating direct engagement in the learning process and fostering scientific curiosity (Indahwati et al., 2023).

Nevertheless, teacher quality also plays a crucial role in shaping students' critical thinking abilities. Effective professional development has been demonstrated to improve pedagogical practices and reinforce the application of critical-thinking skills across disciplines, including physics (Snoek et al., 2011). Educators are therefore expected not only to master subject matter but also to cultivate a culture of inquiry, analysis, and reflection in their teaching (Chouari, 2016). Moreover, the dynamics of globalization present both new opportunities and challenges that require teachers to continuously adapt their instructional strategies in line with evolving social and technological environments (Jin, 2023; Rapoport, 2020; Lam et al., 2023).

Although physics instruction holds great potential for developing critical thinking, there remains a gap between theoretically oriented curricula and real-world applications. This disconnect often leads to low student motivation and engagement, especially in the study of motion dynamics, which can seem abstract (Okono et al., 2023; Anggaryani et al., 2024). Hence, pedagogical innovation is needed to integrate local cultural contexts with physics concepts so that students perceive a direct relevance between what they learn and their daily experiences (Supiyati et al., 2024).

One approach to address this challenge is the development of ethnoscience-based physics teaching materials, which combine scientific knowledge with local wisdom. In this way, students not only learn physical theory but also understand its application in local cultural practices—such as traditional tools or environmental phenomena (Zelviana et al., 2023; Cristy & Pamenang, 2023). This approach is expected to enhance students' critical thinking skills through comparative analysis of cultural practices and modern physics principles, as well as to motivate deeper exploration of scientific concepts (Nisa et al., 2024; Rahayu et al., 2023; Asiyah et al., 2023).

Learning models grounded in local wisdom—employing projects and inquiry—have proven effective in promoting active student engagement while sharpening critical thinking through hands-on experiences in designing, implementing, and evaluating culturally relevant projects. Such models require students to identify cultural phenomena—like constructing traditional fish cages or analyzing fishing boat swings—then formulate research questions, conduct field observations, and analyze data using motion dynamics concepts (Sudarmin et al., 2020; Khoiri et al., 2021). This systematic scientific thinking process facilitates deep reflection, as students must compare experimental outcomes with physics theory and justify any discrepancies, continually honing their analytical and evaluative skills (Fitri & Asrizal, 2023; Telussa & Tamaela, 2023). Within this framework, teachers act as facilitators, guiding each inquiry stage, ensuring research questions are open-ended and challenging, and supporting students in using simple measurement tools—such as stopwatches, meter tapes, and spring scales—to obtain valid empirical data (Nurhasnah et al., 2022).

Enriching teaching materials with multimedia and culture-based teaching aids is also a key strategy for boosting motivation and comprehension of motion dynamics concepts. Integrating images, videos, and interactive simulations that visualize cultural practices—such as bamboo swings in traditional ceremonies or regional dance movement patterns—helps students link abstract phenomena like acceleration and centripetal force to everyday contexts (Prayogi et al., 2023; Verawati et al., 2022). Furthermore, incorporating interactive physics simulation software enables students to manipulate variables such as speed and mass virtually, then compare simulation results with field experiments, allowing them to observe causal relationships directly (Hidayati et al., 2023; Karanggulimu et al., 2021). This blended approach of face-to-face and online learning not only fosters autonomous learning but also builds essential digital skills in a technological age. Thus, ethnoscience-based physics materials can combine hands-on experience with technology-enhanced learning, making motion dynamics concepts more concrete and engaging for students.

In the context of motion dynamics, leveraging ethnoscience examples—such as a study of the Cidomo (traditional horse-drawn carriage)—offers students unique opportunities to observe and measure translational and rotational motion, as well as frictional forces between the wheels and road surface. Through this approach, students compare aspects of classical mechanics with cultural practices, for instance, how drivers adjust speed and steering angle to navigate uneven terrain. Activities like these naturally stimulate critical questioning, such as why vehicle acceleration differs on uphill versus flat tracks and how friction affects the draught animal's energy efficiency (Cholewa et al., 2011; Morales-Doyle, 2017). With worksheet structures that include analytical and reflective guides, students record measurements, formulate hypotheses, and present their findings in simple scientific reports, thereby also exercising their scientific writing and communication skills (Colvin & Tobler, 2013; Nurhasnah et al., 2022). Implementing field-based ethnoscience activities not only enriches the learning experience but also underscores the relevance of physics in local cultural and environmental contexts, making learning more meaningful and motivating students to cultivate curiosity and strong critical-thinking abilities.

The foregoing studies affirm the benefits of ethnoscience in enhancing students' understanding and critical thinking skills. However, gaps remain in the systematic and structured development of teaching materials specifically for motion dynamics. Most studies focus on instructional model implementation without providing comprehensive guidelines for developing ethnoscience-based materials—including teacher guides, student worksheets, and critical-thinking assessments (Nurhasnah et al., 2022; Naz et al., 2023; Moll & Milner-Bolotin, 2009). Moreover, quantitative investigations into the effectiveness of ethnoscience-based materials for improving critical thinking in motion dynamics are still limited. This underscores the need to develop targeted, valid ethnoscience-based physics teaching materials for motion dynamics.

Building on the identified problems, this study aims to develop valid ethnoscience-based physics teaching materials on motion dynamics and to test their practicality and effectiveness in enhancing students' critical-thinking skills. The specific research questions are:

1. How are the ethnoscience-based physics teaching materials on motion dynamics developed to enhance students' critical thinking skills?
2. What are the validity, practicality, and effectiveness of these ethnoscience-based physics teaching materials in improving students' critical-thinking skills?

Novelty of the Study

This study presents a framework for developing ethnoscience-based physics teaching materials on motion dynamics that systematically integrates classical physics concepts with local wisdom. Unlike most previous studies that focused solely on implementing inquiry projects or culture-based learning without structured guidelines, this research designs a complete suite of teaching materials—including instructional modules, teacher guides, student worksheets, and critical thinking evaluation instruments—in an integrated fashion. Consequently, teachers receive step-by-step guidance to facilitate exploration of local phenomena—such as the dynamics of the Cidomo—while students are encouraged to compare their field observations with principles of acceleration, friction, and other physics concepts in a clear and systematic way.

Moreover, this study evaluates the practicality and effectiveness of these materials through field trials and quantitative analyses of students' critical thinking gains. Expert validation and prerequisite testing ensure that the ethnoscience content meets both scientific standards and cultural relevance. The effectiveness study—using pre- and post-tests alongside a critical thinking rubric—provides empirical evidence of significant improvements in students' critical thinking skills on the topic of motion dynamics. This approach demonstrates that ethnoscience not only enriches the learning context but also actively motivates students to think critically, thus bridging the gap between abstract physics theory and their everyday experiences

METHODS

Research Design

This study was designed as a Research & Development (R&D) project focusing on the creation of ethnoscience-based physics teaching materials for the topic of motion dynamics. Its primary goal was to produce materials that not only align with the curriculum but also are rich in local cultural context, thereby enhancing students' critical thinking skills. The ADDIE model (Analyze, Design, Develop, Implement, Evaluate) served as the systematic framework for the entire research process (see Figure 1).

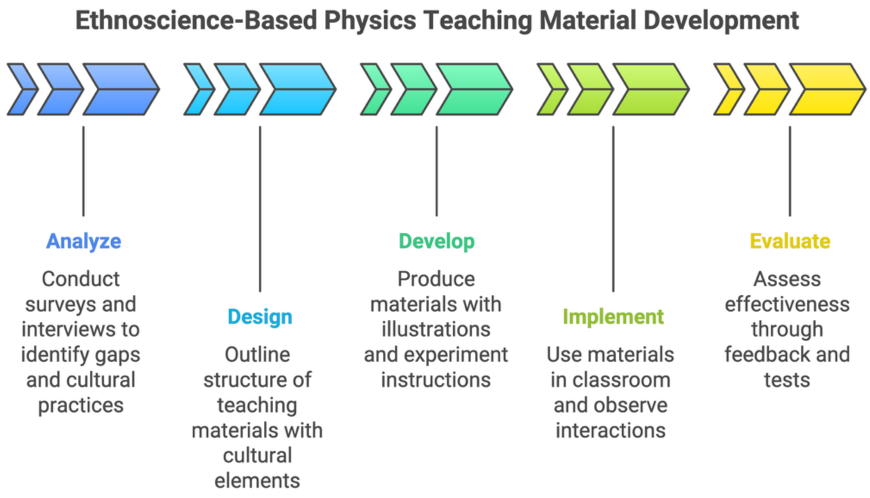

Figure 1. Research and development using the ADDIE model

In the initial Analyze phase, the researchers conducted surveys and interviews with teachers and students to identify gaps in understanding of motion dynamics concepts and to inventory relevant cultural practices, such as the movement of the Cidomo (a traditional Indonesian carriage). This analysis also included mapping learners' characteristics and the available field resources, allowing for the formulation of specific, need-based learning objectives.

During the Design phase, the team outlined the structure of the teaching materials, from learning objectives and summaries of physics theory to local culture exploration activities. In addition to core motion dynamics content—force, acceleration, and Newton's laws—the materials include student worksheets guiding simple field experiments and reflective questions that prompt comparisons between cultural phenomena and physics principles.

In the Develop phase, all components of the teaching materials were produced according to the design specifications, with emphasis on the materials themselves as the primary product. These included illustrations, step-by-step field experiment procedures, and a critical thinking assessment rubric. Once printed, the materials were submitted to a panel of experts for content validation. Their feedback on language clarity, cultural appropriateness, and sufficiency of the assessment instruments was used to revise and refine the materials for greater effectiveness and accuracy.

Implementation took place in a single experimental class, where the teacher used the ethnoscience materials to facilitate face-to-face instruction. The researchers conducted participatory observations, recording interaction dynamics, student engagement, and any practical challenges encountered. Implementation data comprised completed worksheets, group discussion recordings, and field notes illustrating students' responses to the integration of local culture.

Evaluation was carried out both formatively and summatively. Formative evaluation occurred throughout the implementation phase, gathering oral and written feedback from students and the teacher about the teaching materials. The summative evaluation concluded with a physics concept test and an assessment of critical thinking skills using the prepared rubric. Analysis of these evaluation data revealed the extent to which the materials met the learning objectives and identified areas needing further improvement.

By applying all ADDIE phases—from Analyze through Evaluate—this research produced ethnoscience-based physics materials that are not only theoretically valid but also proven effective in practice. The iterative cycle of production, validation, implementation, and evaluation ensured continuous improvement based on empirical evidence, suggesting strong potential for broader and sustainable use in physics education.

Participants and Ethical Considerations

This study involved two validators as expert panel members—both are seasoned practitioners in the development of ethnoscience-based physics instruction. They were selected based on their track record of research and publications related to integrating local wisdom into physics content, as well as their involvement in designing contextualized teaching materials. During the validation process, the experts evaluated the appropriateness of the ethnoscience content, the clarity of the motion dynamics concepts presentation, and the adequacy of the critical-thinking assessment instruments included in the materials.

The field-test participants comprised 20 eighth-grade students at SMP Plus Miftahul Falah, West Lombok, Indonesia. They were chosen through stratified random sampling to ensure balanced representation by gender and academic ability. Prior to testing, the researchers explained the study's objectives and procedures to students, parents, and the supervising teacher. Written informed consent was obtained from the supervising teacher, who also secured parental permission for student participation.

All research procedures received ethical approval from the Educational Research Ethics Committee at Universitas Pendidikan Mandalika and were conducted in accordance with the Helsinki Declaration and human-subject protection guidelines. Detailed information about the study's aims, procedures, and participants' rights was communicated transparently to all stakeholders. Participants were free to withdraw at any time without consequence. Data confidentiality was strictly maintained and used solely for research purposes.

Research Instruments

The research instruments comprised four main tools used to collect data at each stage of developing and evaluating the ethnoscience-based physics materials. The first instrument was a content-validation questionnaire administered to the expert panel prior to field testing. This questionnaire evaluated how well the ethnoscience content was integrated with motion dynamics concepts, the clarity of language and illustrations, and the adequacy of the critical-thinking assessment rubric. Each item employed a five-point Likert scale and included a comments box, allowing validators to offer specific suggestions for revising the teaching materials.

During implementation in the experimental class, a participatory observation sheet was used to record students' questioning and argumentative initiatives, their accuracy in carrying out simple field-experiment procedures, and their ability to relate local cultural practices—

such as measuring the motion of the Cidomo—to underlying physics principles. Observations were supplemented by photographic and audio documentation, which were then organized into structured field notes to support qualitative analysis.

To measure students' critical-thinking skills quantitatively, a ten-item essay test served as the principal assessment. Each essay prompt required students to formulate a problem, propose a hypothesis, analyze their field-experiment data, and draw conclusions by comparing local phenomena with motion dynamics concepts. These items were validated by the expert panel to ensure alignment with the study's objectives, and their reliability was confirmed through internal-consistency analysis (e.g., Cronbach's alpha).

Finally, semi-structured interviews were conducted with the supervising teacher and a selected group of students after the trial. The interview guide addressed topics such as the ease of using the materials, challenges encountered during field activities, and perceptions of the materials' impact on critical-thinking skills. All interviews were recorded, transcribed, and subjected to thematic analysis to add contextual depth and complement the quantitative findings. By combining these quantitative and qualitative instruments, the study gathered comprehensive data to assess the validity, effectiveness, and practicality of the ethnoscience-based physics teaching materials.

Data Analysis

Data from the content-validation process were analyzed first to ensure that the materials' content was appropriate before field testing. The two validators' scores for each questionnaire item were compiled, and the Item-Level Content Validity Index (I-CVI) was calculated as the proportion of validators rating the item as valid (scores of 4–5 on the Likert scale). The average of all I-CVIs yielded the Scale-Level Content Validity Index (S-CVI/Ave), where S-CVI/Ave ≥ 0.90 indicates high content validity (Polit & Beck, 2006). Open-ended comments from the validators were also thematically coded to enrich understanding of needed revisions. Instrument reliability was assessed via Cronbach's alpha, with values ≥ 0.70 considered acceptable (Nunnally & Bernstein, 1994).

Next, students' scores on the ten-item essay test—designed to measure critical-thinking skills—were processed using descriptive statistics to obtain the mean, standard deviation, minimum, and maximum. Score distributions were tested for normality using the Shapiro–Wilk test; if the data met parametric assumptions, a paired-sample t-test was conducted to compare pre- and post-intervention scores. Cohen's d was also calculated to assess the effect size of any changes in critical-thinking ability.

To provide a more detailed picture of individual improvement, the normalized gain (n-gain) was computed as (post-score – pre-score) ÷ (maximum score – pre-score). Gains were classified as high ($g \geq 0.70$), medium ($0.30 \leq g < 0.70$), or low ($g < 0.30$) (Hake, 1998). This n-gain analysis helped reveal the distribution of student responses—such as the percentage achieving high gains—and identify those who might need additional support.

In the qualitative domain, data from participatory observations and semi-structured interviews underwent thematic analysis. Interview transcripts and field notes were subjected to open coding to identify critical-thinking strategies, such as hypothesis selection, experimental data analysis, and cultural reflection. These codes were then grouped into main themes and validated through inter-coder reliability (Cohen's kappa ≥ 0.60), with any interpretive disagreements resolved by consensus.

Finally, quantitative and qualitative findings were triangulated to build a comprehensive understanding. Significant improvements in essay scores and n-gain distributions were integrated with examples of students' critical narratives—such as their comparisons of the "Cidomo" phenomenon with Newton's laws—and teachers' reflections on student engagement. This triangulation strengthened the study's internal validity and elucidated the mechanisms by which ethnoscience-based physics materials fostered the development of critical-thinking skills.

RESULTS AND DISCUSSION

This study was conducted to develop ethnoscience-based physics teaching materials on motion dynamics aimed at enhancing students' critical thinking skills. The research design followed the ADDIE model (Analyze, Design, Develop, Implement, and Evaluate). The findings from each phase are presented as follows.

Analyze

In the Analyze phase, the researchers gathered primary data to inform the development of the ethnoscience materials. An initial survey of 20 eighth-grade students at SMP Plus Miftahul Falah revealed that over 70% of students struggled to understand abstract presentations of force and acceleration concepts, while approximately 65% reported an inability to connect physics formulas with everyday phenomena—such as changes in speed for objects in uniform motion. These findings underscored the need for materials that facilitate students' direct experiences in observing and measuring motion.

In-depth interviews with two science teachers corroborated the survey results. Both teachers acknowledged that conventional teaching materials were highly theoretical and contained few local examples, despite the rich pedagogical potential of phenomena like the motion of the Cidomo—a traditional carriage commonly seen in the surrounding community. They also noted that laboratory aids such as stopwatches and measuring tapes were available but seldom used in field experiments that provide real-world context.

Based on cultural studies and discussions with community leaders, the researchers focused exploration on the mechanics of the Cidomo wheel. Field observations of wheel-speed variations formed the basis for designing the student worksheet and reflective questions. Together, these Analyze-phase findings defined the learning objectives: to develop students' critical thinking skills through contextual observation and comparative analysis of field data and physics principles.

Design

During the Design phase, the researchers crafted the teaching-material framework in line with the Analyze findings and the established learning objectives. This framework comprised five main components: an introduction to motion dynamics concepts, the ethnoscience context of the Cidomo, field-experiment instructions, reflective worksheets, and a critical-thinking assessment rubric. Each component was interwoven—for example, theoretical explanations of force were immediately followed by descriptions of Cidomo wheel mechanics, then by instructions for experiments leveraging those cultural variables. The result was a logically structured outline responsive to students' needs.

Next, detailed content was developed for each unit of the materials. Key terms (force, mass, acceleration) were elucidated using simple diagrams and illustrations of Cidomo activities, rendering abstract concepts tangible. The experiment section specified clear steps: measuring wheel travel distance, recording time intervals, and calculating speed. Each step included practical note boxes to help students record field data efficiently. This design was pilot-tested on paper with the mentoring teachers to assess language suitability and readability.

Student worksheets combined concise closed-ended items with open-ended questions. The latter required students to formulate hypotheses and explain experiment results, while the former checked basic conceptual understanding. A "Cultural Notes" feature prompted students to document observations of social and cultural aspects of the Cidomo—for instance, the role of the draft animal or road conditions—to reinforce links between local context and physics theory.

A teacher's guide was prepared as a companion document, detailing learning objectives, facilitation strategies, and field-experiment troubleshooting tips. Every student-worksheet step was mapped to assessment indicators in the rubric, enabling teachers to conduct consistent critical-thinking evaluations. The resulting prototype guide—complete with diagrams, model answers, and feedback suggestions—was then ready for expert review.

Finally, the entire design underwent a small-scale simulation in the laboratory. Five physics-teacher colleagues reviewed the draft materials and completed an initial feasibility questionnaire. Their feedback indicated that the material structure was logical and language sufficiently clear, though some technical terms needed simplification. The worksheet and teacher's guide were praised as highly useful, while the Cidomo illustrations were recommended to be replaced with actual field photographs. These insights informed the final revisions before entering the Develop phase.

Develop

In the Develop phase, the ethnoscience-based physics teaching materials were fully assembled according to the revised design. The complete manuscript includes explanations of motion dynamics concepts, illustrations of Cidomo mechanics, field-experiment instructions, student worksheets, a "Cultural Notes" box, and a detailed critical-thinking assessment rubric. The layout employs a single-column format with full-color illustrations and ample space for student annotations. A glossary of technical and ethnoscience terms was added as an appendix to facilitate comprehension. All these elements were combined into a single prototype document, ready for validation. The cover of the Cidomo ethnoscience teaching book is shown in Figure 2.

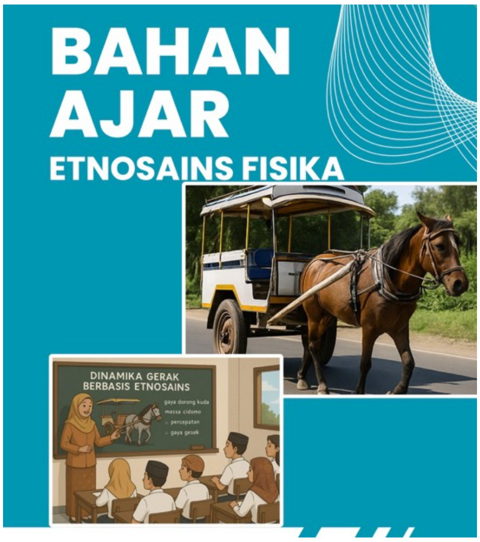

Figure 2. Excerpt from the ethnoscience context textbook

Next, the results of the content validation of the ethnoscience-based physics teaching materials by two expert validators—showing their evaluation scores, qualifications, the average S-CVI, and internal reliability (Cronbach's alpha)—are presented in Table 1.

Table 1. content validation results by two expert validators

Aspect	Score (Percentage)	Qualification
Validator 1, evaluation score	90%	Highly Feasible
Validator 2, evaluation score	82%	Highly Feasible
Average S-CVI	86%	Highly Feasible
Cronbach's alpha (reliability)	0.88	High Internal Consistency

Content validation was conducted by two experts in ethnoscience-based science education. Based on a 25-item questionnaire, Validator 1 awarded a score of 90% ("Highly Feasible") and Validator 2 scored 82% ("Highly Feasible"), yielding an average S-CVI of 86% ("Highly Feasible"). The Item-Level CVI (I-CVI) for most items exceeded 0.80, indicating that the majority of items were rated valid by both validators. Internal reliability analysis of the materials—measured via Cronbach's alpha on the validation scores—produced a value of 0.88, reflecting high and trustworthy item consistency.

Qualitative comments from the validators supplemented the quantitative data and informed further revisions. These comments are summarized in Table 2.

Table 2. Qualitative comments from expert validators

Validator	Comments and Suggestions
Validator 1	• Include clear bibliographic references in the teaching materials • Deepen the treatment of the highlighted ethnoscience components

Validator	Comments and Suggestions
Validator 2	• Add licensing statements for images or use freely licensed images • Move the reference list to the end and include a glossary of physics and ethnoscience terms

Validator 1 emphasized the need to include clear bibliographic references and to deepen the examination of the highlighted ethnoscience components. Validator 2 proposed adding licensing statements for images or using freely licensed images, moving the reference list to the end, and including a glossary of physics and ethnoscience terms. All of these suggestions were grouped under the themes of references, visuals, and terminology, then integrated into the teaching materials. The glossary was expanded, the bibliography relocated, and image license labels were added to each page of illustrations.

After expert validation revisions, the prototype materials were trialed in a limited simulation with five physics teachers as participants. These teachers conducted the material's activities for two hours in the school laboratory while the researchers observed practical challenges and ease of use. Participatory observations showed that the field-experiment instructions were easy to follow and that the critical-thinking rubric helped teachers assess consistently. The teachers suggested improving the placement of field photographs for better visual contrast and focusing the reflective questions to avoid overly broad prompts. Final revisions addressed these points by adjusting photo layouts and refining question scope before the full field implementation.

The Develop phase results indicate that the ethnoscience-based physics materials have matured in terms of content, format, and practical usability. The cycle of production, expert validation, and teacher simulation effectively identified and corrected shortcomings, ensuring that the materials are not only theoretically and culturally valid but also classroom-ready. With adequate I-CVI and S-CVI/Ave values, strong expert support, and positive feedback from the teacher simulation, the materials are now ready for the field-testing phase (Implement). All components—text, illustrations, assessment instruments, and worksheets—have been finalized in a version prepared for wide dissemination.

Implement

The Implement phase was conducted over two 90-minute sessions in a single experimental class of 20 eighth-grade students at SMP Plus Miftahul Falah. The teacher began by reiterating the learning objectives and demonstrating how to use the ethnoscience-based physics materials, then divided the students into five groups (four per group) to carry out a field experiment using the Cidomo as the study object. The researchers conducted participatory observations, noting each student's level of engagement, group dynamics, and any technical obstacles that arose.

Table 3 summarizes student participation and achievements during the experiment. Nineteen students (95%) immediately took the initiative to begin measurements, and all five groups (100%) successfully recorded both the distance and time data for the Cidomo's motion. Furthermore, sixteen students (80%) posed critical questions regarding variations in acceleration or frictional force, fifteen students (75%) formulated hypotheses before the experiment, and fourteen students (70%) were able to justify their measurement results based on physics concepts.

Table 3. Student participation and achievement in the implement phase

Indicator	Number (%)	Notes
Total students	20	–
Students who actively began the experiment	19 (95%)	1 student required encouragement from the teacher
Groups that successfully recorded data	5 (100%)	All groups recorded both distance and time measurements
Students asking critical questions	16 (80%)	Questions concerned variations in acceleration/friction
Students formulating initial hypotheses	15 (75%)	–
Students justifying experimental results	14 (70%)	Based on the concepts of force and acceleration

Although overall implementation success was high, several practical challenges were identified. The bright sun on the schoolyard caused some groups' data quality to suffer, as students became fatigued quickly. Additionally, three of the first groups struggled to set experimental parameters correctly and experienced confusion reading the instructions. Table 4 details these challenges along with the corrective actions taken.

Table 4. Practical challenges and remedial actions in the implement phase

Challenge	Frequency	Remedial Action
Difficulty setting experimental parameters	3 groups	Re-demonstration by the teacher
Student fatigue due to intense heat	Whole class	Brief rest breaks
Confusion reading the experiment instructions	1 group	Immediate clarification by the teacher

During the discussion and reflection sessions, the teacher used the critical-thinking rubric to evaluate each group's brief report. Observations showed that follow-up questions such as "Why does the *Cidomo*'s acceleration differ on an incline?" successfully focused the discussion on conceptual analysis. Teacher feedback also noted that the "Cultural Notes" box in the materials encouraged students to explore the social context of the *Cidomo*, thereby boosting both motivation and the perceived relevance of the lesson.

Overall, the Implement phase demonstrated that the ethnoscience-based physics materials are practical for facilitating active engagement and critical thinking. Quantitative and qualitative data from observations, worksheets, and discussions support the readiness of the materials to proceed to the Evaluate phase, with recommendations to provide sunshade for field experiments and to consider more stable measuring instruments.

Evaluate

The Evaluate phase analyzed both pre-test and post-test data from 20 students, as well as the distribution of normalized gain (n-gain), to measure improvements in critical-thinking skills following the intervention. Quantitatively, the mean pre-test score was 17.75 (SD = 4.93), which increased to a mean post-test score of 78.75 (SD = 5.65). Shapiro–Wilk tests confirmed that both score distributions were approximately normal ($p > 0.05$). A paired-sample t-test yielded $t_{(19)} = 38.99$, $p < 0.001$, indicating a statistically significant increase in post-test scores. The effect size, Cohen's d = 5.50, reflects a very large practical impact.

Table 5. Descriptive statistics and paired-sample t-test for pre-test and post-test scores (n = 20)

Statistic	Pre-test	Post-test	Δ (Post–Pre)	t-value	p-value	Cohen's d
Mean	17.75	78.75	+61.00	38.99	< 0.001	5.50
Standard Deviation (SD)	4.93	5.65	—	—	—	—
Range (Min–Max)	10–30	70–90	—	—	—	—

All 20 students (100%) achieved a "high" n-gain ($g \geq 0.70$), with an average n-gain of 0.845, confirming that every student experienced substantial gains in critical-thinking skills.

Table 6. Distribution of critical-thinking n-gain scores (n = 20)

n-Gain Category	Range	Number of Students	Percentage
High	$g \geq 0.70$	20	100%
Medium	$0.30 \leq g < 0.70$	0	0%
Low	$g < 0.30$	0	0%

Qualitative data from semi-structured interviews were analyzed thematically to complement the quantitative findings. Table 7 summarizes three emergent themes—"Increased Self-Confidence," "Deep Critical Reflection," and "Relevance of Local Context"—along with brief descriptions and representative interview excerpts.

Table 7. Qualitative themes from interviews, with descriptions and sample excerpts

Theme	Brief Description	Sample Interview Excerpt
Increased Self-Confidence	Students reported greater confidence in formulating hypotheses and responding to critical questions after seeing real-world applications of *Cidomo*.	**Interviewer:** *"How did you feel when asked to make a hypothesis before the experiment?"* **S1:** *"I was nervous at first, but after seeing the examples in the materials, I knew how to predict more accurately."*
Deep Critical Reflection	Post-intervention essays exhibited more systematic argument structures and use of field data to support conclusions.	**Interviewer:** *"What did you learn by comparing field data with physics theory?"* **S12:** *"I learned that theory alone isn't enough; we must prove it with numbers. That made my conclusions stronger."*
Relevance of Local Context	Integrating the *Cidomo* practice made physics feel more meaningful	**Interviewer:** *"Did these materials help you relate physics to your surroundings?"*

Theme	Brief Description	Sample Interview Excerpt
	and motivated students to explore further.	**S7:** *"Yes—since I often see Cidomo, now I can calculate its speed and understand why it's fast or slow."*

Inter-coder reliability for the thematic analysis was computed using Cohen's kappa to ensure consistency between coders.

Table 8. Inter-coder reliability for thematic analysis (Cohen's Kappa)

Measure	Value	Description
Observed Agreement (P_o)	0.85	Proportion of analysis units coded identically by both coders
Expected Agreement (P_e)	0.35	Probability of chance agreement based on each coder's distribution of codes
Cohen's Kappa (κ)	0.72	$(P_o – P_e) \div (1 – P_e)$; indicates "substantial agreement" between coders

Finally, triangulating the quantitative and qualitative results confirmed that the intervention significantly enhanced students' critical-thinking skills. The combination of large gains in essay-test scores, uniformly high n-gain values, robust thematic evidence ($\kappa = 0.72$), and teacher observations of student engagement demonstrates the efficacy of the ethnoscience-based physics materials in fostering critical thought.

Triangulating the statistically significant results, the uniformly high n-gain distribution, and the positive qualitative narratives confirms the effectiveness of the ethnoscience-based physics materials in enhancing students' critical-thinking skills on motion dynamics. Recommendations for future development include diversifying the cultural phenomena studied and refining the reflective-question guides to sustain and broaden the intervention's impact.

Overall, the findings demonstrate that teaching materials integrating the local "Cidomo" phenomenon into motion dynamics instruction successfully improved students' critical-thinking abilities. Students not only applied force and acceleration concepts in a real-world context but also formulated hypotheses, analyzed field data, and justified their findings with greater confidence. In addition, deep critical reflection and appreciation for the local context strengthened their learning motivation, thereby achieving the study's goal of developing and testing the effectiveness of ethnoscience-based materials.

The significance of these results lies in the power of cultural relevance to bridge the gap between abstract physics theory and students' everyday experiences. Observing the *Cidomo* in action naturally prompted "why" and "how" questions rather than rote acceptance of formulas. This inquiry process fostered a scientific mindset: students actively gathered data, verified hypotheses, and engaged in critical discussions about the variables affecting their experimental outcomes. Thus, ethnoscience materials facilitated both higher cognitive and emotional engagement compared to conventional approaches.

These findings align with Prayogi et al. (2023), who reported that ethnoscience learning models encourage students to reflect on cultural values while honing critical-thinking skills through inquiry experiments. Similarly, Irfandi et al. (2023) observed progressive gains in critical-thinking from Malay ethnoscience materials, although our study's print-based, single-cycle design differs in format. The modular approach's ease of replication in low-tech settings represents a notable advantage. Studies by Mardana et al. (2022) and Verawati et al. (2022) emphasize that linking physics concepts to local traditions—such as regional games—reinforces understanding and critical skills. Our research extends these insights to the *Cidomo* context, confirming that a variety of local phenomena can enrich physics education. Furthermore, Risdianto et al. (2020) and Sunarti et al. (2024) support the efficacy of direct, ethnoscience-based modules in boosting critical-thinking n-gains, underscoring their relevance when online resources are scarce.

Practically, this study's implications cover four areas. First, physics curricula should incorporate ethnoscience modules using locally relevant cultural phenomena as experimental bases, allowing each school to choose contexts most pertinent to their students. Second, teacher training must prepare educators to design and facilitate field experiments with attention to logistics, ethics, and safety. Third, policymakers should support the development and distribution of these modular materials and facilitate collaborations with cultural experts and local practitioners. Fourth, ethnoscience integration can be promoted as a strategy to strengthen 21st-century skills—including creativity and collaboration—consistent with recommendations by Nurhasnah et al. (2022).

Future research should explore other ethnoscience phenomena—such as traditional games, local agricultural practices, or cultural rituals—as objects of physics experimentation. Comparing the effectiveness of these modular print materials with online or flipped-classroom ethnoscience models (Putri et al., 2023) could yield further insights into each approach's strengths and limitations. In this way, ethnoscience will continue to serve as an innovative bridge between scientific knowledge and local wisdom, enriching learning experiences and preparing students to meet future challenges.

CONCLUSION

The development of ethnoscience-based physics teaching materials on motion dynamics has proven to be valid, practical, and effective in enhancing students' critical-thinking skills. The ADDIE process—from needs analysis through evaluation—yielded materials that integrate the local Cidomo cultural context with physics concepts, engaging students actively in observation, experimentation, and scientific reflection. The high n-gain results and positive qualitative narratives confirm that this intervention successfully fostered students' confidence, analytical abilities, and perceived relevance of learning.

Furthermore, the ethnoscience materials effectively bridged the gap between abstract physics theory and students' everyday experiences. By directly measuring and discussing the motion of the Cidomo, students were prompted to think critically—formulating hypotheses, comparing field results with theory, and justifying their findings—which ultimately strengthened their conceptual understanding. This success underscores the importance of local context as a catalyst for both cognitive and affective engagement.

Consequently, this study affirms that integrating ethnoscience into physics instruction not only deepens conceptual comprehension but also facilitates the development of students' critical-thinking skills. The materials developed have the potential for replication in various regions using locally relevant cultural phenomena, making them a flexible and meaningful pedagogical model.

LIMITATIONS

This study was limited to a single cultural phenomenon—the motion of the Cidomo—and one school location, so caution is required when generalizing the results. The implementation period was relatively brief (two sessions), which may not fully capture long-term development of critical-thinking skills. Additionally, limited laboratory resources and field weather conditions affected the smoothness of the experiments, occasionally leading to suboptimal variable measurements.

RECOMMENDATION

Future work should develop ethnoscience teaching materials based on multiple local phenomena—such as traditional games, agricultural practices, or cultural rituals—and extend the implementation period to provide a more comprehensive view of critical-thinking development. Comparative studies using online or flipped-classroom ethnoscience models could also offer valuable insights into the relative effectiveness of each approach.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Conflict of Interests

The authors declare no conflict of interest.

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