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The Feasibility and Effectiveness of a Physics Enrichment Book Based on Ethnophysics of the Borobudur Temple

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Abstract: This study aims to explore ethnophysical concepts embedded in Borobudur Temple and to develop a contextual physics enrichment book for senior high school students. Indonesia possesses a rich cultural heritage with strong potential for contextualized science education, and Borobudur Temple—an architectural masterpiece that embodies various physics principles—offers a unique opportunity to design culturally relevant learning resources. The research employed a Research and Development (R&D) approach using the AM3PU3 model and a one-group pretest–posttest design involving 74 students from SMA Negeri 1 Tengaran. Data were collected through expert validation, student questionnaires, and pretest–posttest scores, and analyzed using the N-Gain test. The findings indicate that mechanical concepts grounded in ethnophysics are present in the temple's structure and can support culturally based physics instruction. The developed book received expert validation scores of 3.40 for content, 3.83 for language, and 3.63 for presentation (on a 1–4 scale). Student responses were also high, with scores of 4.00 for readability, 3.98 for effectiveness, and 3.90 for design (on a 1–5 Likert scale). The N-Gain result of 0.30 indicated a moderate improvement. These findings suggest that integrating ethnophysics may serve as a culturally responsive strategy to enhance students' conceptual understanding and engagement in science education.

Keywords: Ethnophysics, Borobudur Temple, Contextual Learning, Physics Enrichment Books

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Introduction

The 2022 Programme for International Student Assessment (PISA) revealed that Indonesian students scored an average of 383 in science literacy, compared to the OECD average of 476 (OECD, 2023). These findings underscore the importance of strengthening students' ability to understand and apply scientific concepts in daily life. The World Bank (2023) also highlights the urgency of improving 21st-century skills such as critical thinking, problem-solving, and scientific literacy in developing nations, including Indonesia. Rather than viewing this as a limitation, it represents a call to advance science instruction that is both cognitively demanding and contextually relevant (Trilling & Fadel, 2009; Kemendikbudristek, 2023a).

One promising avenue for such reform is the integration of local cultural contexts into science learning. Ogawa (1995) introduced the concept of indigenous science, referring to knowledge systems rooted in local traditions that complement formal science education. Studies in Indonesia have shown that ethnoscience-based learning can enhance students' learning motivation (Fitriah, 2021; Husin et al., 2018). Other research has reported the development of ethnoscience-based physics teaching materials that are effective in improving learning outcomes (Haspen & Syafriani, 2020; Hikmawati, Muhlis, & Subhan, 2024). In addition, the integration of traditional knowledge into science learning has been proven to strengthen conceptual understanding and character values (Sudarmin, 2014; Sudarmin & Asyhar, 2012).

Meta-analysis studies have shown that ethnoscience-based learning can enhance students' critical thinking skills (Idul & Fajardo, 2023). Other studies have found that this approach also strengthens science process skills and conceptual mastery (Pieter & Risamasu, 2024). Moreover, integrating local wisdom into physics learning has a positive impact on students' scientific literacy and creativity (Tusa'diah et al., 2024; Hikmawati & Suastra, 2023).

A specific application of ethnoscience in physics education is ethnophysics, which embeds physics concepts within traditional practices and cultural artifacts. Evidence suggests that ethnophysics-based learning can improve students' creativity, motivation, and higher-order thinking skills, while strengthening their connection to local culture (Laos & Tefu, 2022; Ilhami et al., 2021; Mahmudah et al., 2023). It has been implemented to teach topics such as mechanics and waves (Fianti & Neratania, 2024) and has also been applied in teaching energy concepts (Manasikana et al., 2024; Sholahuddin & Admoko, 2021).

Borobudur Temple, a UNESCO World Heritage Site, offers a rich contextual environment for ethnophysics instruction. Its architecture demonstrates various physics principles, including pressure distribution, mechanical stability, geometric symmetry, acoustic resonance, and solar orientation (Haldoko et al., 2014; Sutopo et al., 2011). Its interlocking stone system illustrates earthquake resistance, while corridors and reliefs optimize lighting, airflow, and spatial balance. Such features create meaningful opportunities for contextualized instruction in statics, wave behavior, energy, and thermodynamics.

Despite increasing interdisciplinary research on Borobudur in fields such as mathematics and archaeoastronomy (BRIN, 2022), its physical features remain underutilized in physics education. A recent review indicates limited integration of ethnoscience into Indonesian physics instruction, especially in relation to cultural heritage sites (Kasim et al., 2023). This study addresses this gap by developing, validating, and evaluating a physics enrichment book based on Borobudur's ethnophysical characteristics. The objectives are to: (1) identify relevant physics phenomena in the temple's structure and design; (2) integrate these into culturally contextualized learning materials; and (3) assess the feasibility and effectiveness of the materials in improving students' conceptual understanding of physics.

Methods

.This study employed a Research and Development (R&D) approach adopting the AM3PU3 model developed by Santyasa (2015). This model consists of eight sequential stages: (A) needs analysis, (M1) problem identification, (M2) theoretical review, (M3) empirical data collection and analysis, (P1) initial product design, (U1) small-scale field testing, (U2) main field testing, and (U3) (final/large-scale field testing). This model was selected because it provides a systematic procedure for producing educational products with a strong theoretical foundation, empirical validation, and potential for practical application.

Research Context and Participants

The study was conducted at SMA Negeri 1 Tengaran, Semarang Regency, Central Java, in February 2024. The research subjects comprised 74 students from three classes: X6 (25 students), XI-10 (24 students), and XII MIPA 6 (25 students). Three classes were purposively selected based on the relatively homogeneous academic abilities within each grade level, making them representative for evaluating the enrichment book. The selection was also constrained by the limited time available for the study, resulting in only three classes being included in the research.

Development Procedures

The development stages followed the AM3PU3 procedures as follows. Needs Analysis (A) was conducted through a literature review of scientific journals, books, and online sources to identify physics concepts embedded in Borobudur Temple. Observations in bookstores and in the online repository of the Ministry of Education revealed the absence of senior high school physics enrichment books based on the Borobudur context. Unstructured interviews were conducted with archaeologists from Sebelas Maret University, researchers from the Borobudur Conservation Center, and administrators of the Sangha Theravāda Mendut to explore the educational potential of the site.

Problem Identification (M1) synthesized the findings from the needs analysis, highlighting the scarcity of contextual teaching materials integrating cultural heritage. The selected topics, aligned with the Merdeka Curriculum, included rigid-body equilibrium, static electricity, Newton's laws, conservation principles, fractal patterns, and the astronomical orientation of Borobudur.

Theoretical Review (M2) involved examining relevant theories and research findings on ethnoscience, ethnophysics, and contextual science learning. The scope of the material was aligned with the senior high school physics syllabus in the Merdeka Curriculum to ensure consistency with national education standards.

Empirical Data Collection and Analysis (M3) was carried out through interviews, official documents from the Borobudur Conservation Center, and digital archives. Bibliometric mapping was also conducted using VOSviewer software (Van Eck & Waltman, 2010) to visualize keyword networks and identify research gaps in ethnophysics and contextual science education.

Initial Product Design (P1) resulted in the first draft of the Borobudur-based ethnophysics enrichment book by integrating selected physics concepts with the temple's physical characteristics. This draft was validated by two physics education experts and one cultural heritage expert. Based on their feedback, the draft was revised into a second version, and subsequently refined into a third draft.

Main field Testing (U2) was conducted in February 2024 using a One Group Pretest–Posttest design (Sugiyono, 2010). In the first week, students took a pretest and received the enrichment book, then studied it independently at home for one week. In the second week, a posttest was administered, followed by the completion of the readability questionnaire and the collection of open-ended feedback from students.

The U1 (small-scale field testing) and U3 (final/large-scale field testing) stages were not conducted in this study due to time constraints. This decision was based on the flexibility principle of development models as described by Santyasa (2015) and supported by Sugiyono (2019) as well as Gall, Gall, and Borg (2003), which emphasize that the stages in research and development can be modified or simplified according to objectives, field conditions, and resource limitations. Product revision was carried out directly after U2 based on expert validation results, pretest–posttest data, readability questionnaires, and student feedback. Thus, although the third-stage product testing was not conducted, the study produced a product that had undergone expert validation and empirical testing in the main field trial.

Research Instruments

The research instruments used in this study comprised four main components: (1) expert validation sheets to assess content, language, and presentation aspects using a 4-point Likert scale, based on the Non-textbook Assessment Instrument from the Ministry of Education, Culture, Research, and Technology (n.d.); (2) a readability questionnaire to assess clarity, effectiveness, and visual appearance using a 5-point Likert scale; (3) an open-ended feedback form for students; and (4) pretest–posttest instruments consisting of four essay questions covering rigid-body equilibrium, static electricity, and fractal patterns.

Data Analysis Techniques

Quantitative Data Analysis

The quantitative data analysis in this study aimed to evaluate the feasibility and effectiveness of the physics enrichment book based on the ethnophysics of the Borobudur Temple. The feasibility evaluation encompassed the book's validity, assessed by experts, as well as its readability and attractiveness from the perspective of students as the end users. Furthermore, the book's effectiveness was measured by comparing the improvement in students' understanding through pre-test and post-test scores. This quantitative approach provided objective evidence that complemented the qualitative analysis results, enabling a comprehensive and integrated evaluation of the learning product.

The book's validity was examined through assessments by three expert validators from the fields of physics and cultural heritage. They evaluated the content, language accuracy, and presentation aspects using a 4-point Likert scale. The average score across these three aspects was calculated to determine the overall feasibility level of the book.

Meanwhile, the book's readability was evaluated using a 5-point Likert scale questionnaire completed by 74 students. The average score from this questionnaire provided insights into the level of readability and interest in the book from the users' perspective. Therefore, the validity assessment covered not only academic aspects but also practical aspects related to the book's applicability in learning contexts.

To measure the book's effectiveness, a normality test was first conducted on the pre-test and post-test data using the Kolmogorov–Smirnov test. This method was deemed appropriate for large samples (>50 participants) (Razali & Wah, 2011). The results indicated that the data were normally distributed, allowing the use of parametric statistical analysis. Learning effectiveness was then assessed using the normalized gain (N-Gain) approach, which calculates the proportional increase in students' scores relative to the maximum achievable score. The N-Gain formula used was:

$$N_{gain} = \frac{Skor_{Posttest} - Skor_{Pretest}}{Skor_{Maks} - Skor_{Pretest}} \quad (1)$$

The interpretation of N-Gain values is classified as follows:

Table 1. Normalized N-Gain Criteria

N Gain Value	Gain Category
$0{,}7 \le N_{Gain} \le 1{,}0$	High
$0{,}3 \le N_{Gain} < 0{,}7$	Moderate
$0{,}0 < N_{Gain} < 0{,}3$	Low
$N_{Gain} = 0{,}0$	No improvement

Qualitative Data Analysis

Qualitative data were obtained from written feedback provided by expert validators and students. Both expert validators and students offered comments covering the content, language, and presentation aspects of the enrichment book. Student feedback played a crucial role in ensuring the quality and readability of the learning material. Kahraman and Koray (2020) indicated that standardized feedback, whether oral or written, can enhance content clarity and align learning materials with learners' needs.

The feedback from both groups was manually analyzed by identifying emerging themes, grouping similar information, and interpreting its meaning in the context of book development. To enhance the reliability of the findings, source triangulation was applied by comparing the results from expert validators and students. The results of this analysis served as the basis for revising and refining the enrichment book.

Results and Discussion

Ethnophysical Concepts Identified in Borobudur Temple

The needs analysis was carried out through a comprehensive review of scientific articles, conservation literature, and digital archives, as well as unstructured interviews with experts. These included archaeologists from Sebelas Maret University, administrators from the Sangha Theravāda Indonesia Mendut, and a researcher from the Borobudur Conservation Center.

The analysis of the literature and interview data revealed that Borobudur Temple contains numerous physical phenomena relevant to physics instruction. These include the use of dry stone construction without adhesive materials, which provides structural stability against seismic activity (Brahmantara, Muhsidi, & Wahyudi, 2008; Haldoko, Muhammad, & Purwoko, 2014); the strategic placement of reliefs in relation to the sun's position, reflecting the use of natural lighting; and the weathering of stone structures caused by environmental factors such as temperature and humidity (Sutopo et al., 2011; Yanuardi, 2018). Other findings include the mechanical wear of temple stones due to friction (Balai Konservasi Borobudur, 2020) and the architectural design of corridors intended to resist the sagging of structural walls over time (Ismijono et al., 2013; Suhartono et al., 2017).

The bibliometric network visualization shown in Figure 1 illustrates the mapping of co-occurring keywords from 500 scientific publications related to the themes of "physics" and "Borobudur Temple," indexed between 2014 and 2024. This mapping was generated using VOSviewer software as part of the needs analysis stage in this study, aiming to identify research patterns and thematic gaps in existing literature.

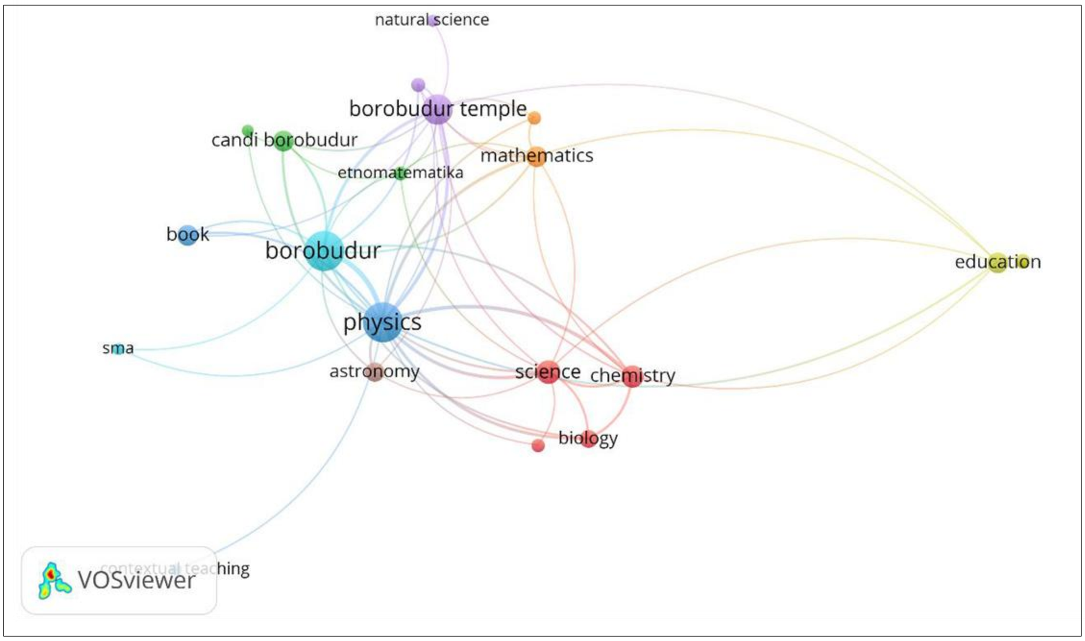


Figure 1. Co-occurrence network of keywords from publications on "physics" and "Borobudur Temple" (2014–2024), visualized using VOSviewer software.

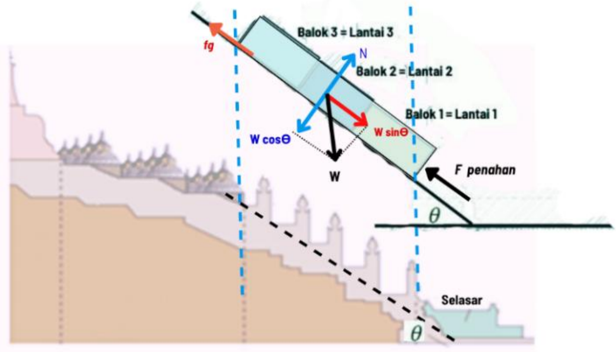
The map reveals several distinct keyword clusters. The red cluster includes terms such as science, chemistry, and biology, reflecting the dominance of studies in the field of pure science. The yellow cluster centers on education, while the blue cluster incorporates terms like borobudur, physics, astronomy, and book, indicating a thematic overlap between scientific and cultural domains. The green cluster consists of keywords such as candi borobudur and SMA, the orange cluster includes mathematics, and the purple cluster features natural science and borobudur temple. While physics appears moderately connected to borobudur and astronomy, its association with education is notably weak. Moreover, the keyword ethnophysics does not appear in the visualization at all, suggesting a lack of scholarly attention to this specific intersection.

These patterns point to a clear research gap at the intersection of physics education and local cultural heritage. The absence of the term ethnophysics, along with the limited integration of physics and education in the context of Borobudur, underlines the need for academic initiatives that bridge this divide. Therefore, the development of a physics enrichment book grounded in Borobudur ethnophysics is both timely and relevant. Such a resource is not only positioned to support contextual and culturally responsive science learning but also to contribute meaningfully to the body of literature by promoting the integration of science, culture, and education.

Book Characteristics

The enrichment book developed in this study integrates physics concepts with local cultural elements. Its primary cultural reference is the Borobudur Temple. The instructional content does not rely solely on abstract physical formulations, but rather embeds concepts such as force, energy, equilibrium, torque, and static electricity within tangible cultural contexts. For instance, normal force and friction are explained through the interlocking mechanism of stones in the stupa structure. Meanwhile, static electricity is introduced via the natural phenomenon of lightning, which is contextually linked to the pointed shape of the stupa's apex—encouraging students to reflect on its potential alignment with the principles of a lightning rod. Although no direct scientific research has confirmed such a connection, this reflective approach fosters scientific reasoning grounded in observation and interpretation.

The book is also designed to be relevant to the students' real-life environment and experiences. Visual representations, contextual narratives, and case studies derived from cultural heritage sites enable students to perceive the relationship between classroom physics and the world around them. For example, Figure 2 illustrates how the Borobudur corridor is modeled as a tiered inclined plane to explain the principles of resisting force and friction. This visual strategy facilitates the construction of conceptual understanding in a concrete manner.



Gambar 3.6 Balok tertahan di bidang miring (lantai 1 hingga 3 dimisalkan sebagai sebuah balok)
(Gambar latar belakang diolah dari: buku Lestari Cagar Budayaku, 2018 hal.44)

Berdasarkan gambar di atas kita dapat membuat persamaan berdasarkan hukum I Newton. Hukum I Newton kita gunakan pada sistem ini, karena keadaan benda yang sedang diam. Menurut hukum I Newton total gaya yang bekerja pada selasar adalah nol, dapat juga kita simpulkan bahwa gaya yang searah gerak benda memiliki besar sama dengan gaya yang berlawanan dengan arah gerak benda.

W sinΘ berlawanan arah terhadap $F_{penahan}$. Gaya gesek balik (lantai candi) bernilai nol karena balok (lantai candi) dalam keadaan diam.

Sehingga diperoleh persamaan :

$F_{penahan} = W \sin\Theta$

Ingat bahwa W = mg

Sehingga dapat ditulis: $F_{penahan} = mg \sin\Theta$

Figure 2. An excerpt from the book illustrating the function of the Borobudur Temple corridor in explaining the principles of resisting force and friction.

Furthermore, the book also includes a discussion of fractal patterns as an additional exploratory topic. Fractals are geometric patterns that repeat at different scales and have been widely studied in various fields of science (Bunde & Havlin, 1994). Although fractals are not a core component of the school physics curriculum, their recurrence in the architectural forms and layout of Borobudur is presented as an opportunity for students to explore mathematical patterns within science. This section broadens students' perspectives on geometric regularities in both cultural and natural settings and emphasizes that science can also be interpreted through the lens of historical architectural heritage.

Through this approach, the book serves not only as an informational resource but also as a tool to cultivate analytical thinking skills. It helps students expand their scientific horizons and deepen their connection to their cultural identity. These benefits reflect the insights of Mohd Isa et al. (2022), who emphasize that integrating cultural contexts into science education enhances its relevance and meaning, especially in diverse learning environments.

Validity of Book

The validity of the book was assessed by three expert validators, consisting of two physics education experts and one expert on Borobudur Temple. These validators evaluated the content accuracy of both the physics and Borobudur-related materials, as well as the clarity of the language and the appropriateness of the presentation. A summary of the validation results is presented in Table 2.

Table 2. Average Score of Each Aspect

No	Rated aspect	Average Score	Category
1	Physics Material	3.40	High
2	Language	3.83	High
3	Presentation	3.63	High

Based on the validation results, the book meets the eligibility standards, receiving high ratings across all assessed aspects. This indicates that the content aligns with correct physics concepts, employs clear and accessible language, and is presented in an engaging manner suitable for student

Book Readability

Evaluating the readability of the book from the students' perspective is essential to assess the usefulness and practicality of the developed material. According to Reeve (2013), involving students in evaluating instructional materials provides valuable insights into the clarity, attractiveness, and ease of understanding of the content.

In this study, the book's readability was assessed through a questionnaire consisting of several statements related to the clarity of explanations, language simplicity, the role of illustrations in supporting comprehension, and the accuracy of text formatting. Based on the results of the questionnaire completed by student participants, the average readability scores for each section of the book were obtained. The complete results are presented in Table 3.

Table 3. Student Readability Assessment of the Enrichment Book

No	Assessed Aspect	Score	Average Score	Category
1	Clarity of explanations	3.9		
2	Language clarity and readability	4.0		
3	Effectiveness of images in supporting understanding	4.2	3.98	High
4	Accuracy of text formatting	3.8		

Based on the data presented in Table 3, the readability of the enrichment book is classified as high, with an overall average score of 3.98 across all assessed aspects. Students provided positive evaluations, particularly in the clarity of explanations, language accessibility, and the use of images to support understanding. The highest score was given to the role of images (4.2), indicating that visual elements were highly effective in reinforcing the presented concepts. Meanwhile, the clarity of language (4.0) and formatting accuracy (3.8) also received favorable ratings. These results suggest that the book is not only easy to comprehend but also visually and structurally appropriate for use in classroom and independent learning contexts. The high level of readability demonstrates the book's potential to engage students and facilitate the learning of physics concepts in a culturally contextualized manner.

Book Effectiveness

The effectiveness of the developed enrichment book was assessed using a normality test and an N-Gain analysis. Results from both the Kolmogorov–Smirnov and Shapiro–Wilk tests indicated that the pre-test and post-test data were normally distributed ($p = 0.200$), meeting the assumptions for parametric analysis (Field, 2022).

The N-Gain test was used to evaluate learning improvement. Gain values were interpreted using standard thresholds: low (< 0.3), medium (0.3–0.7), and high (> 0.7) (Sukarelawan, Yudianto, & Suryati, 2021). The scores for classes X-6, XI-10, and XII MIPA-6 were 0.34, 0.16, and 0.39, respectively, suggesting moderate improvement in X-6 and XII, and low in XI-10. The average gain (0.30) reflects a moderate effect overall (see Table 4).

Table 4. Results of the N-Gain Test for Pre-Test and Post-Test Questions

Class	N-Gain Score	Gain Category
X6	0.34	Moderate
XI-10	0.16	Low
XII MIPA 6	0.39	Moderate
Average Score	0.30	Moderate

These findings indicate that the book positively influenced conceptual understanding, though the learning gains remain modest. Several contributing factors may explain this outcome. The limited implementation period—just one week—likely constrained students' ability to engage deeply with the content. Contextual learning, especially when integrating cultural elements such as the structure and philosophy of Borobudur Temple, requires sufficient time for reflection and comprehension (Tomlinson, 2001; Sari & Wulandari, 2021).

Motivational differences among students also played a role. Grade XII students, already committed to the science stream, demonstrated higher engagement. Meanwhile, students in Grades X and XI, still in academic exploration phases, showed varying interest. According to Hidi and Renninger (2006), interest development occurs progressively, and motivation significantly influences media-based learning outcomes. Nugroho (2015) similarly notes that learners with higher intrinsic motivation interact more meaningfully with instructional materials.

Additionally, students experienced challenges in transferring physics concepts to cultural contexts. Effective knowledge transfer depends on both conceptual depth and contextual familiarity (Bransford et al., 2000). Without strong foundational knowledge, students struggle to connect abstract content to real-world cultural practices. Mayer (2009) emphasizes that visualization and engagement are critical for successful contextual learning.

Grade XI students achieved the lowest N-Gain score (0.16). Two factors may account for this. First, the book's content aligned more directly with the mechanics topics studied in Grade X. Grade XI students were engaged with topics like fluid dynamics and wave motion, which had less overlap with the enrichment material (Squires, 2012). Second, many Grade XI students reported lower interest in physics, potentially due to their transitional academic status. These findings align with previous research highlighting the role of interest and motivation in academic achievement (Chen, 2024; Harefa et al., 2023).

Beyond these pedagogical aspects, broader implementation challenges remain. Many students lack sufficient cultural or scientific literacy to contextualize the material without guidance (Hidi & Renninger, 2006). Teachers also face difficulties using enrichment texts due to time constraints and curriculum demands (Kasim et al., 2023; Squires, 2012). Moreover, the absence of national policy frameworks for integrating cultural content into science education further limits classroom adoption (Kemendikbudristek, 2023).

To address these constraints, structured support is essential. This may include teacher professional development, digital access to contextual resources, and collaboration between science educators and cultural experts (Isa, Bunyamin, & Phang, 2022). These measures could improve the book's usability and promote more effective integration of ethnophysics-based materials in diverse educational settings.diverse school contexts.

Input from Expert Validators and Students

The expert validator specializing in Borobudur Temple suggested that the structural explanation of the temple should not be limited to stone-locking techniques but should also include information on modern reconstruction efforts, such as the concrete casting applied to the temple floor. Additionally, the expert recommended a review of the sections discussing fractal patterns and the role of stupas as potential lightning rods. In response, the chapter on fractal patterns was retained, with revisions aimed at encouraging students' critical thinking skills (see Figure 3).

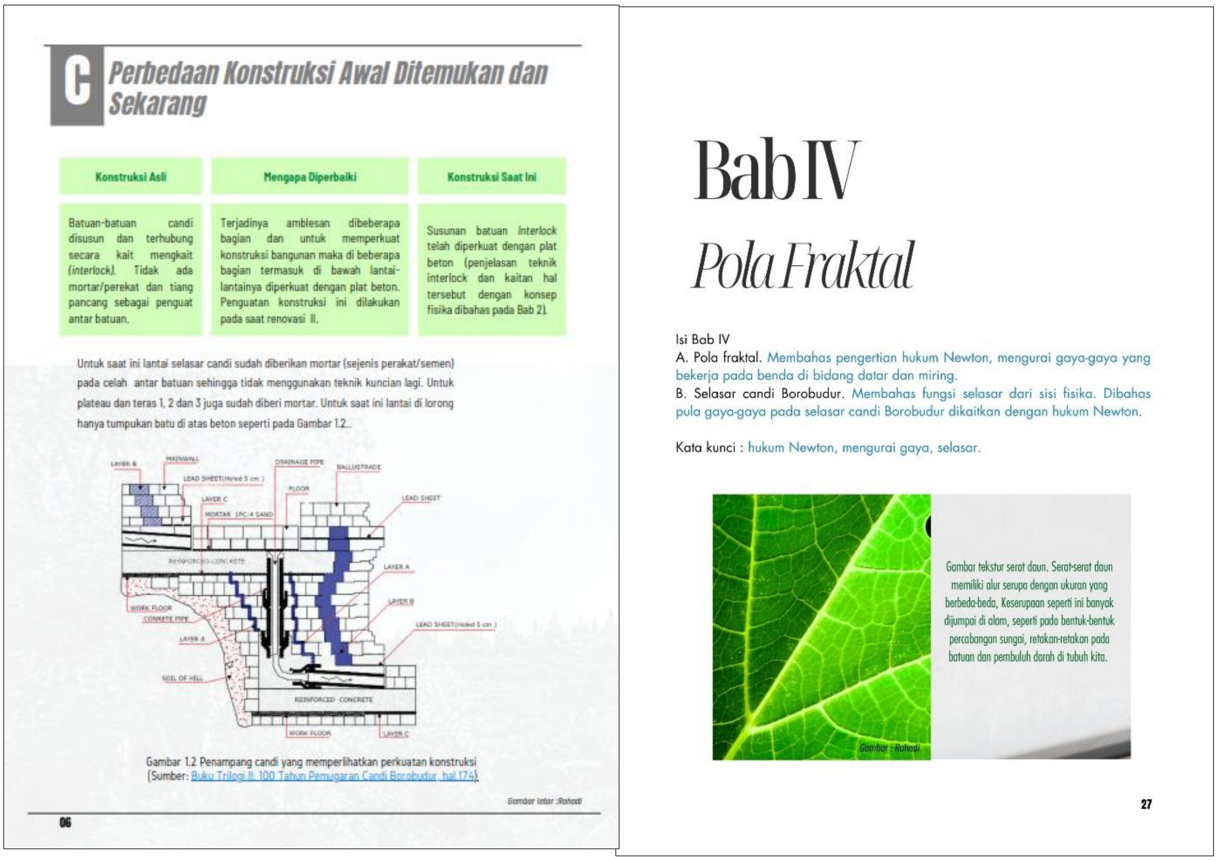


Figure 3. Example of Supplementary Book Material on Post-Restoration Construction and Fractal Patterns

The physics expert validator recommended that the physics content be presented with greater depth and organized more systematically. Additionally, it was suggested that each image be accompanied by a clear and credible source reference. In response, revisions were made to the relevant sections to enhance the material's validity and academic rigor. Meanwhile, the media expert emphasized the importance of incorporating 21st-century skills, particularly critical thinking and self-reflection. These suggestions were addressed by adding reflective questions, including enrichment materials, and providing a digital version of the book with embedded links to relevant online resources (Figure 4).

Figure 4. Examples of online resources integrated into the enrichment book

From the user perspective, students as respondents also provided valuable feedback. A total of 74 comments were collected, with most focusing on visual design, clarity of explanations, and content engagement. Several students also expressed appreciation for the book's format, describing it as visually appealing and offering a unique and enjoyable learning experience. Based on the test results and feedback, revisions were made to the content and appearance. The final book integrates 21st century skills (4C) and is equipped with digital links for enrichment (Figure 5)

Figure 5. Final version of the book cover

Conclusion

This study confirms that the ethnophysics-based enrichment book on Borobudur Temple is valid and feasible for use in physics instruction. The material enhanced students' understanding of mechanics, with a moderate level of improvement based on N-Gain analysis. These findings highlight the strong potential of integrating cultural contexts to support concept acquisition in science education.

However, this study has several limitations. The small-scale field testing (U1) and final/large-scale field testing (U3) stages were not conducted due to time and resource constraints. The effectiveness test was implemented over a short period (one week) and involved a limited sample of three classes from a single school. In addition, the enrichment book was used in a self-learning setting without intensive teacher facilitation, which may have influenced student engagement and comprehension. Future research with a broader scope, longer implementation period, and integration of interactive media, reflective learning tasks, and cultural site visits is recommended to maximize the effectiveness and sustainability of this enrichment book's implementation.

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