Journal of Information Technology Education: Innovations in Practice

An Official Publication of the Informing Science Institute
InformingScience.org

JITEiip.org

Volume 24, 2025

AI-DRIVEN ETHNOSCIENCE LEARNING: ENHANCING PHYSICS EDUCATION THROUGH MALAY CULTURAL INSIGHTS

Jufrida Jufrida	Universitas Jambi, Jambi, Indonesia	jufrida@unja.ac.id
Wawan Kurniawan*	Universitas Jambi, Jambi, Indonesia	kurniawan_wawan@unja.ac.id
M. Furqon	Universitas Jambi, Jambi, Indonesia	mfurqon@unja.ac.id
Khairul Anwar	Universitas Jambi, Jambi, Indonesia	mathanwar@unja.ac.id
Hebat Shidow Falah	Universitas Jambi, Jambi, Indonesia	hebatshidowfalah@unja.ac.id
Cicyn Riantoni	Universitas Jambi, Jambi, Indonesia	cicynriantoni@unja.ac.Id

* Corresponding author

ABSTRACT

Aim/Purpose	This study aims to explore the innovative integration of machine learning techniques into project-based learning rooted in Malay ethnoscience in Jambi, Indonesia. The research introduces a novel framework that utilizes educational data mining to personalize culturally responsive STEM education in under-resourced public schools.
Background	Ethnoscience, particularly ethnophysics, provides a culturally relevant context for learning, connecting scientific principles to traditional practices. In Jambi, rich traditions such as the construction of stilt houses and the preparation of local cuisine reflect underlying principles of physics and sustainability. Integrating these practices into education is crucial for enhancing students' critical thinking and contextual understanding.
Methodology	This research adopts a mixed-methods approach, combining qualitative analysis of Malay ethnoscience practices with data mining techniques to extract patterns and correlations from educational data. Project-based learning modules were designed based on insights derived from data mining algorithms applied to student performance and engagement metrics.

Accepting Editor Martin D Beer | Received: January 13, 2025 | Revised: April 4, April 23, 2025 | Accepted: May 16, 2025.
Cite as: Jufrida, J., Kurniawan, W., Furqon, F., Anwar, K., Falah, H. S., & Riantoni, C. (2025). AI-driven ethnoscience learning: Enhancing physics education through Malay cultural insights. *Journal of Information Technology Education: Innovations in Practice, 24,* Article 13. https://doi.org/10.28945/5520

Contribution	The study contributes a unique model combining cultural heritage with predictive analytics to optimize learning design. Unlike existing AI-driven systems, this model embeds local wisdom as a predictive variable, enabling contextualized learning recommendations grounded in students' sociocultural identities.
Findings	Key findings include a 25% increase in student engagement and a 15–20% improvement in understanding physics concepts among students engaged in culturally embedded hands-on projects. Machine learning algorithms (Random Forest and Naïve Bayes) achieved up to 85% accuracy in predicting student success, identifying prior cultural familiarity and level of active engagement as the most influential predictors.
Recommendations for Practitioners	Educators are encouraged to use data mining tools to personalize learning and incorporate local wisdom into curricula. Culturally rooted project-based learning has proven effective in enhancing student engagement.
Recommendations for Researchers	Further studies are needed to expand the application of data mining in ethnoscience education across other cultural contexts. Researchers should explore the scalability of such frameworks and the integration of additional machine learning algorithms to enhance prediction accuracy.
Impact on Society	By bridging traditional knowledge with modern AI, this study offers a scalable model for culturally inclusive education. It demonstrates how local wisdom can be leveraged through machine learning to promote both academic excellence and cultural preservation, particularly in public education systems facing resource constraints.
Future Research	Future work should focus on the development of interactive tools and digital resources to support project-based ethnoscience learning. Studies should also investigate the long-term impact of integrating ethnoscience into formal education on cultural preservation and academic performance.
Keywords	educational data mining, project-based learning, ethnoscience, Malay culture, Jambi, machine learning, cultural heritage, educational technology

INTRODUCTION

Education plays a critical role in shaping both the intellectual and cultural fabric of society. In the face of globalization, traditional knowledge systems risk being marginalized, underscoring the urgency of integrating local wisdom into modern education. Ethnoscience, a field that bridges scientific principles with indigenous practices, emerges as a promising strategy to create meaningful and culturally relevant learning experiences. This approach allows students to contextualize abstract scientific concepts within their environment, fostering critical thinking, deeper engagement, and cultural preservation (Asmayawati et al., 2024; Fuad et al., 2022; Parwati et al., 2018).

Indonesia, with its vast cultural diversity, offers immense potential for incorporating ethnoscience into formal education. In regions like Jambi, Malay, ethnoscience includes rich traditions such as the construction of stilt houses, traditional agricultural practices, and local culinary methods. These practices reflect scientific principles such as structural stability, thermodynamics, and sustainability, providing unique and relatable contexts for teaching STEM (science, technology, engineering, and mathematics) subjects. For example, the construction of stilt houses involves physics principles like load distribution and structural mechanics, while traditional cooking techniques highlight concepts of heat transfer and efficiency (Noviana et al., 2023; Nyssa et al., 2022; Sumarni et al., 2022).

While prior studies have explored ethnoscience integration in education, they often focus on either urban private schools or pilot programs with strong institutional support. This study uniquely examines public school students in Jambi—many of whom face systemic limitations such as limited digital access, under-resourced classrooms, and varying levels of teacher readiness. These contextual differences allow for new insights into how culturally integrated project-based learning functions in constrained yet culturally rich environments (Rizvi, 2023; Sutrisno et al., 2023).

Despite growing interest in culturally responsive education, current research rarely addresses how ethnoscience-based learning can be systematically personalized using AI in under-resourced public school systems. Most studies are either qualitative in nature, lack predictive frameworks, or are implemented in private or well-funded school contexts. There is also limited empirical evidence on how specific ethnoscientific practices can be transformed into structured, high-impact STEM learning activities. This gap is particularly evident in Indonesia's public education sector, where cultural richness coexists with systemic limitations. Therefore, there is an urgent need to develop a scalable, data-driven model that integrates local wisdom, AI-driven personalization, and project-based learning to improve both academic and cultural outcomes in public schools.

Machine learning, a branch of AI, offers powerful tools to analyze and interpret complex educational data, providing actionable insights to enhance teaching and learning (Sharma & Sharma, 2023; Tapalova & Zhiyenbayeva, 2022). Recent studies have demonstrated the effectiveness of various machine learning approaches in predicting student performance and identifying at-risk learners (Alshamaila et al., 2024; Korchi et al., 2023). In the context of ethnoscience education, machine learning algorithms can be utilized to identify patterns in student engagement, predict learning outcomes, and recommend tailored interventions that align with both cultural and academic goals. For example, machine learning models such as Random Forest or Naïve Bayes can analyze student performance data to determine which project-based activities—like constructing stilt houses or exploring traditional cooking techniques—yield the most significant learning gains (Idowu, 2024; Nair et al., 2023; Ramaswami et al., 2019). Educational data mining applications have shown promise in handling big data in higher education contexts (Alshareef et al., 2020; Bai et al., 2021), while these insights can then be used to design culturally relevant and effective learning modules, ensuring that traditional knowledge is not only preserved but also meaningfully integrated into the curriculum (Dasmahapatra et al., 2023).

In Jambi, the application of machine learning can address persistent challenges in implementing ethnoscience-based education. By analyzing large datasets, such as student performance metrics and engagement levels, machine learning systems can provide educators with predictive analytics to identify at-risk students and recommend personalized learning pathways (Sutrisno et al., 2023). Additionally, these systems can help bridge gaps in teacher training by offering data-driven guidance on how to effectively incorporate local wisdom into STEM education. For instance, algorithms can highlight which aspects of Malay ethnoscience, such as architectural principles in stilt houses or thermodynamic concepts in traditional cooking, are most effective in improving student understanding of scientific concepts (J. Jufrida et al., 2021; Parmin & Fibriana, 2019).

Furthermore, AI-powered tools can facilitate the development of interactive learning environments that make ethnoscience more accessible and engaging. Virtual simulations, augmented reality (AR), and gamified applications supported by AI can bring traditional practices to life, allowing students to explore complex cultural concepts in a hands-on, immersive manner (He, 2023; Schutte, 2020). These technologies not only enhance student engagement but also provide scalable solutions for integrating ethnoscience into diverse educational settings (A. Sholahuddin et al., 2021). The integration of AI in K-12 education has shown particular promise when combined with culturally responsive approaches (Eguchi et al., 2021), while recent advances in educational technology emphasize the importance of contextualizing learning within students' cultural frameworks (Velander et al., 2024).

The aim of this research is to develop and evaluate how the integration of Malay ethnoscience, artificial intelligence (specifically machine learning), and project-based learning can improve student

learning outcomes in physics within public education contexts in Jambi, Indonesia. Specifically, the study aims to: (1) identify effective culturally embedded learning patterns through ethnoscience practices such as traditional stilt-house construction and indigenous cooking methods; (2) leverage machine learning algorithms to systematically predict and enhance students' comprehension and engagement; and (3) develop a scalable framework that combines these elements into personalized, culturally responsive educational interventions, contributing to both academic achievement and the preservation of local cultural heritage.

The contribution of this research is threefold. First, it highlights the potential of machine learning to personalize and enhance ethnoscience-based learning experiences (Essa et al., 2023). Second, it provides a scalable framework for integrating traditional knowledge into formal education, addressing challenges such as limited resources and teacher training (Rizvi, 2023). Third, it offers a model for how AI can be harnessed to support culturally responsive education, contributing to global discourses on equitable and inclusive learning practices (Jyoti et al., 2024).

Moreover, conducting this study within the public education system in Jambi, Indonesia, adds a critical dimension to its originality. Public schools in this region often face systemic challenges such as limited technological infrastructure, constrained resources, and varying levels of teacher readiness to adopt advanced educational technologies. These conditions mirror the realities in many developing regions, making the insights from this study highly relevant to a broader international audience. At the same time, the richness of Jambi's Malay cultural heritage—such as traditional stilt-house construction, bamboo cooking, and indigenous games—offers authentic scientific contexts that remain underutilized in mainstream curricula. By integrating these cultural practices into AI-supported learning models within the constraints of public schools, this study proposes a scalable and adaptable educational framework that responds to both academic and cultural needs. It also aligns with national education goals that emphasize character development, science literacy, and cultural preservation, reinforcing the potential of this framework to influence educational policy and curriculum reform.

This study addresses the following research questions:
RQ1: How does the integration of Malay ethnoscience into project-based learning affect student engagement and conceptual understanding in physics?
RQ2: How can machine learning algorithms be used to personalize culturally responsive learning experiences in public schools?
RQ3: Are there any notable differences in engagement and performance across different types of Malay ethnoscientific practices or among students from different ethnic backgrounds?

In summary, this study underscores the transformative potential of combining ethnoscience, AI, and project-based learning to create meaningful educational experiences (Kurniawan et al., 2019; Yu et al., 2024). By addressing both the academic and cultural dimensions of education, this research offers valuable insights for educators, researchers, and policymakers seeking to integrate traditional wisdom into modern educational frameworks. The findings of this research are expected to contribute significantly to the discourse on culturally responsive education, demonstrating the transformative potential of blending local knowledge with modern technology (Farshad et al., 2024). Moreover, the framework developed in this study could serve as a model for other regions, promoting the scalability and adaptability of culturally integrated educational strategies.

LITERATURE REVIEW

ETHNOSCIENCE IN SCIENCE EDUCATION

Ethnoscience refers to the integration of local and indigenous knowledge into science curricula, offering contextual relevance that enhances student engagement and learning outcomes. Several studies have confirmed the pedagogical value of cultural practices—such as stilt-house construction, lemang cooking, and indigenous games—when applied to scientific concepts like thermodynamics, load

distribution, and sustainability (Jufrida et al., 2021; Parmin & Fibriana, 2019). Research has shown that traditional games like gasing can effectively demonstrate physics concepts such as rotational dynamics (Nuari et al., 2019; Rizaldi et al., 2023), while traditional food preparation methods provide authentic contexts for exploring thermodynamic principles (Salman et al., 2021). These practices not only facilitate conceptual understanding but also promote cultural identity and pride among students (Noviana et al., 2023).

Studies on ethno-STEM education have demonstrated the effectiveness of integrating local wisdom with modern pedagogical approaches. For instance, Maryanti et al. (2023) developed ethno-STEM e-modules that successfully enhanced creative thinking abilities, while Ansumarwaty and Doyan (2023) analyzed the feasibility of ethnoscience-based learning tools for improving scientific literacy. Additionally, research on Malay cultural practices in Jambi has revealed rich opportunities for physics education, including the study of traditional customs and their scientific foundations (Fadilah et al., 2019).

Despite the demonstrated benefits, much of the existing literature on ethnoscience remains descriptive. Most studies rely on qualitative approaches and reiterate similar advantages without offering empirical evaluations of scalable instructional models. Few scholars address how ethnoscientific content can be tailored to meet individual learning needs, especially in public education contexts with limited resources. This study addresses that gap by repositioning ethnoscience as a dynamic variable within a personalized learning framework supported by artificial intelligence. Rather than treating cultural content as static curriculum material, it is analyzed as a key input in machine learning algorithms to customize student learning pathways based on cultural familiarity.

AI-Driven Personalization in Education

Artificial intelligence (AI) and machine learning (ML) have increasingly been applied in education to support data-informed decision-making and personalized learning. AI tools have proven effective in identifying at-risk learners, predicting academic success, and recommending learning resources tailored to individual performance profiles (Sharma & Sharma, 2023; Tapalova & Zhiyenbayeva, 2022). Algorithms such as Random Forest and Naïve Bayes are commonly used for classification and prediction in learning analytics (Dasmahapatra et al., 2023; Idowu, 2024; Nair et al., 2023).

Recent advances in educational data mining have expanded the possibilities for personalized learning. Alfanz et al. (2023) demonstrated successful student performance prediction at Sultan Ageng Tirtayasa University, while Ayala Franco et al. (2021) developed predictive models for academic risk in computing careers. The integration of AI with educational assessment has shown promise in various contexts, from predicting college placements (Kumar et al., 2023) to analyzing student employability (Jayasree & Baseer, 2018). Advanced techniques combining multiple algorithms, such as Random Forest with ANFIS methods, have achieved high accuracy in evaluating professional student achievements (Mojsilović et al., 2023).

Machine learning approaches have also been successfully applied to physics education specifically. Zabriskie et al. (2019) used machine learning to predict physics course outcomes, while Santoso et al. (2022) employed thematic analysis with machine learning to analyze Indonesian physics education research literature. These studies demonstrate the versatility of AI in enhancing physics education through data-driven insights.

However, these studies predominantly focus on cognitive or behavioral indicators and are often conducted in high-resource environments. Sociocultural variables—such as prior knowledge rooted in local traditions—are rarely considered in AI-based personalization models. This lack of cultural responsiveness limits the applicability of AI in diverse, real-world educational settings.

The current study responds to this limitation by embedding students' familiarity with local ethnoscientific practices into ML models as predictive features. For instance, a student with prior exposure to traditional architecture may receive project-based tasks centered on stilt-house construction,

reinforcing both scientific and cultural competencies. This approach expands the scope of personalization beyond academic metrics to include cultural context, a dimension that is largely missing in prior AI-focused research.

Furthermore, AI-powered tools can support the creation of immersive, culturally grounded learning environments. Technologies such as augmented reality (AR), virtual simulations, and gamified platforms allow students to interact with traditional practices in meaningful and engaging ways (He, 2023; Schutte, 2020). These innovations make ethnoscience more accessible while promoting scalability and engagement across diverse educational contexts (A. Sholahuddin et al., 2021).

Project-Based Learning in Culturally Diverse Contexts

Project-based learning (PjBL) is a student-centered pedagogical model that promotes inquiry, collaboration, and critical thinking. It has been widely recognized for its capacity to connect learning with real-world applications, particularly in STEM education (Kurniawan et al., 2019; A. Sholahuddin et al., 2021). When PjBL incorporates local wisdom or traditional knowledge, it can further enhance students' intrinsic motivation and cultural connection to the subject matter (He, 2023). Research has shown that ethnoscience-based project-based learning significantly improves students' creative thinking skills (Rahayu et al., 2023) and scientific literacy (Nurmaliati et al., 2023).

The integration of technology with culturally responsive PjBL has shown promising results. For instance, mobile devices have been used as physics laboratories to explore rotational dynamics (Wheatland et al., 2021), while traditional games like gasing have been analyzed for their physics content (M. I. Sholahuddin & Admoko, 2021). These approaches demonstrate how modern technology can enhance the exploration of traditional practices in science education.

Recent studies have also emphasized the importance of comprehensive approaches to educational data analysis. Ray and Saeed (2018) explored applications of big data analytics in higher education, while Prokofieva (2023) demonstrated the integration of data analytics in teaching with machine learning. These advances suggest that combining AI-driven personalization with culturally embedded content can create more effective learning experiences.

However, existing PjBL models are typically uniform in design, assuming equal relevance and effectiveness across all student groups. Personalization is rarely applied in the context of culturally embedded projects, and few studies explore how AI might be leveraged to recommend or adjust project content based on learners' cultural backgrounds or prior experiences.

This study addresses this need by combining the pedagogical strengths of PjBL with the adaptive potential of machine learning. By analyzing data on student engagement and cultural familiarity, the system can assign projects—such as modeling traditional houses or conducting experiments based on local food preparation—that align with both scientific objectives and students' personal experiences.

Research Gap and Contribution

Although each of the three domains—ethnoscience, AI personalization, and project-based learning—has been explored individually, their integration remains underdeveloped, particularly within public school systems in developing regions. Current literature often neglects how culturally responsive content can be adapted dynamically using AI technologies.

This study proposes and evaluates a novel framework that unifies these elements into a scalable, AI-supported, culturally embedded model for physics education in public schools. Using established algorithms (e.g., Random Forest, Naïve Bayes), the system analyzes student data to generate culturally aligned project recommendations. In doing so, it offers a new approach to personalized learning that is both data-driven and culturally sustainable, filling a critical gap in the educational technology literature.

RESEARCH METHODOLOGY

This study employed a mixed-methods research design, combining quantitative and qualitative approaches to strengthen the validity of findings and provide both statistical and contextual depth. The quantitative component consisted of structured data collection from student learning outcomes and engagement metrics, which were later analyzed using machine learning algorithms (Random Forest and Naïve Bayes). The qualitative component included observations and teacher interviews to identify culturally embedded learning patterns and to interpret the results of the algorithmic recommendations. A total of 150 students from public secondary schools in Jambi participated in this study. These students were sampled using stratified random sampling, based on school location and grade level, from a total population of approximately 620 students across four schools. The response rate was 94%, as 141 complete datasets were obtained for analysis. Prior to analysis, the data were cleaned and validated to remove outliers and incomplete entries. To ensure data reliability, internal consistency was checked using Cronbach's Alpha for engagement and performance metrics, which yielded values above 0.80, indicating high reliability. The machine learning models were tested using 10-fold cross-validation to evaluate their predictive accuracy. By clearly defining the methodology, this study ensures transparency in how data were collected, interpreted, and applied to the AI-driven personalization framework. Furthermore, the integration of qualitative and quantitative insights supports the formulation of a conceptually grounded contribution to both physics education and educational data science.

QUALITATIVE APPROACH: GATHERING CULTURAL INSIGHTS

To ensure an authentic representation of Malay ethnoscience, this research utilizes in-depth interviews with key informants, including local cultural practitioners, educators, and community leaders. The selection of participants follows a purposive sampling method, targeting individuals with extensive knowledge of traditional practices, such as stilt house construction and games like *gasing*. A semi-structured interview guide was developed, focusing on uncovering the scientific principles embedded in these practices. Triangulation is employed by corroborating interview data with observations and relevant literature to enhance validity and reliability (Cheron et al., 2022).

The qualitative data were not only used to identify relevant ethnoscientific practices but also served as a foundational layer to interpret the outcomes of project-based learning. Themes from interviews helped explain why certain cultural activities—such as lemang cooking—led to deeper conceptual understanding. These narratives provided cultural and emotional context to quantitative improvements, enhancing the interpretive strength of the mixed-methods design.

QUANTITATIVE APPROACH: DATA ANALYSIS AND PREDICTION

The quantitative component involves the use of machine learning algorithms, specifically Random Forest and Naïve Bayes, to analyze educational data and predict student outcomes. The dataset includes anonymized student performance records collected from pilot implementations of ethnoscience-based project modules. Prior to analysis, the dataset undergoes preprocessing to ensure quality and minimize bias, including techniques such as normalization and missing value imputation. Predictive algorithms are applied to identify factors influencing student engagement and success, enabling educators to design targeted interventions tailored to individual needs (Nantschev et al., 2020).

INTEGRATION OF METHODS

The integration of qualitative and quantitative data is achieved through a triangulated analysis framework. Qualitative insights gathered from interviews inform the design of project-based learning modules, while quantitative predictions guide the personalization of these modules to maximize learning outcomes. For instance, cultural practices like constructing stilt houses are transformed into hands-on physics activities, demonstrating principles such as load distribution and structural stability.

Meanwhile, predictive analytics provide real-time feedback, helping educators identify at-risk students and recommend culturally relevant interventions (Hands, 2022; Searle et al., 2022).

Data Collection and Analysis

Data collection encompasses three core instruments: interview guides, machine learning systems, and project modules. Interview guides are used to capture qualitative data on traditional practices, ensuring that the integration of ethnoscience into education remains authentic and culturally grounded. Machine learning systems analyze quantitative data to identify patterns in student behavior and performance. Project modules serve as practical tools for project-based learning, connecting abstract scientific concepts to real-world applications rooted in local culture (Higginbottom, 2004).

The data analysis phase employs a combination of descriptive and inferential statistical methods. Descriptive analysis provides a detailed understanding of student engagement with ethnoscience-based projects, categorizing levels of interaction and identifying effective teaching strategies. Inferential statistics validate the study's hypotheses by measuring the impact of cultural relevance on student outcomes. Predictive algorithms enhance this analysis by forecasting potential learning gaps and offering actionable insights for improving curriculum design.

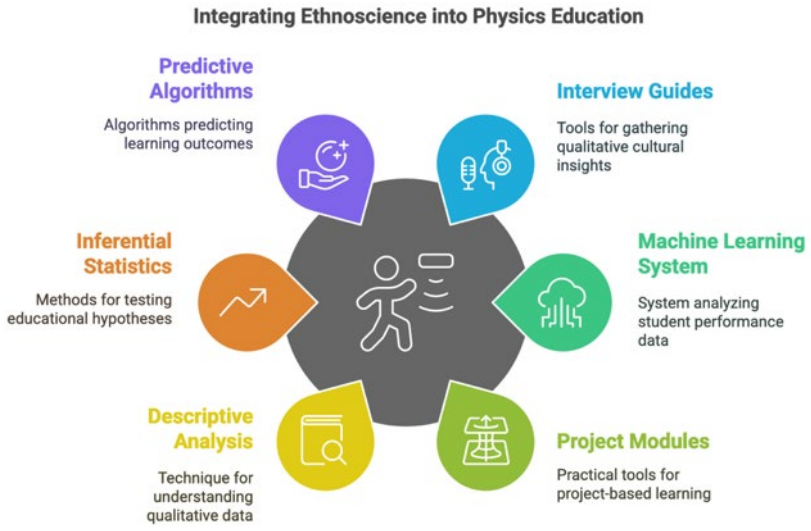

Figure 1: Integrating ethnoscience into physics education: tools and techniques

Figure 1 illustrates the comprehensive approach used in this study to integrate ethnoscience into physics education. The diagram presents six key components that work synergistically: Predictive Algorithms forecast learning outcomes based on student data, Interview Guides capture qualitative cultural insights from community members, Machine Learning Systems analyse performance patterns, Project Modules provide hands-on culturally relevant activities, Descriptive Analysis examines engagement levels, and Inferential Statistics validate the educational impact. Each component plays a critical role in achieving the study's objectives by addressing both the cultural and scientific aspects of education.

Figure 2 provides an overview of the research process framework, highlighting the connections between research instruments, data analysis techniques, and expected outcomes. The diagram emphasizes the iterative nature of the methodology, where insights from qualitative and quantitative approaches converge to achieve enhanced student understanding, identification of learning patterns, and the development of inclusive educational practices. This comprehensive framework

demonstrates how traditional knowledge can be systematically integrated with modern analytical tools to create effective learning experiences.

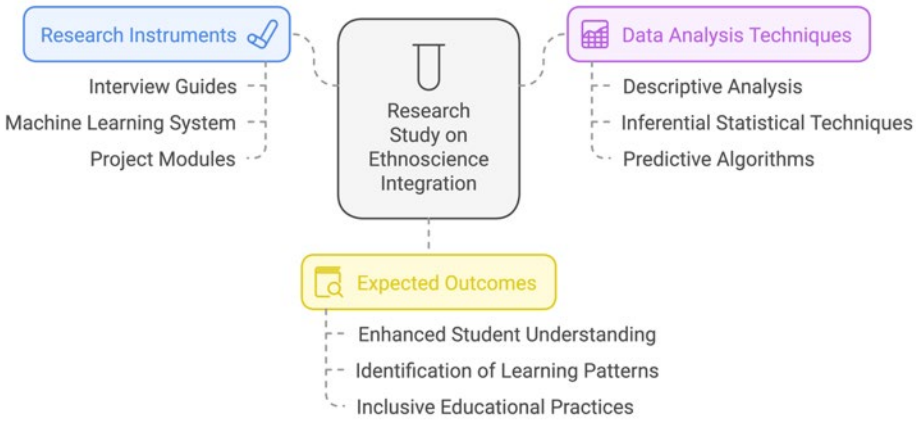

Figure 2: A comprehensive framework for ethnoscience integration in education: tools, analysis, and outcomes

Evaluation and Validation

To ensure the effectiveness of the proposed framework, the study implements a multi-layered evaluation strategy. First, the validity of the project-based learning modules is tested through pilot studies involving both teachers and students. Feedback is gathered via surveys and focus group discussions, enabling iterative refinement of the modules. Second, the reliability of machine learning predictions is assessed using cross-validation techniques, ensuring that the algorithms remain robust and generalizable across different datasets. Finally, the overall impact of the integrated approach is measured longitudinally, evaluating its influence on student engagement, academic performance, and cultural appreciation over time (Vital et al., 2021).

Generalizability and Adaptability

While this study focuses on the Malay ethnoscience practices of Jambi, the proposed framework is designed to be adaptable to other cultural contexts. By providing clear guidelines for integrating traditional knowledge with modern pedagogical tools, the study offers a replicable model for educators in culturally diverse settings. Future research could explore its application in other regions, enriching the global discourse on sustainable and inclusive education.

In conclusion, this research methodology combines cultural authenticity with advanced analytics, creating a holistic approach to integrating ethnoscience into physics education. By balancing qualitative insights with data-driven methods, the study not only enhances learning outcomes but also contributes to the preservation of indigenous knowledge systems, aligning with global efforts to promote equity and sustainability in education (Hastuti et al., 2019).

Machine Learning Algorithms and Tools

This study adopts a mixed-methods approach to explore the integration of Malay ethnoscience into project-based learning, supported by machine learning and data mining techniques (Martinez-Plumed & Hernández-Orallo, 2023). The research combines qualitative analysis of traditional Malay practices in Jambi with quantitative modeling using machine learning algorithms to optimize and personalize learning strategies. The qualitative component involved in-depth interviews with local cultural practitioners, educators, and community leaders. These interviews, combined with observations and document reviews, focused on identifying scientific principles embedded in traditional practices such as

stilt house construction and traditional games like *gasing*. This cultural data provided the foundation for designing project-based learning modules that are both academically rigorous and culturally relevant.

The quantitative component applied machine learning techniques to analyze student performance and engagement data collected from pilot implementations of ethnoscience-based projects. Data sources included assessments, engagement metrics, and project evaluations from 150 students participating in culturally embedded learning activities. Various studies have demonstrated the effectiveness of similar approaches in predicting student performance (Ahamad & Ahmad, 2021; Syed Mustapha, 2023), providing a foundation for our analytical framework. To ensure data quality, preprocessing steps included cleaning and normalization to remove outliers and inconsistencies, while missing values were imputed using mean substitution for numerical variables and mode for categorical variables. Min-Max normalization was used to scale features for comparability. Two machine learning algorithms were employed: Random Forest and Naïve Bayes. Random Forest was chosen for its robustness in handling high-dimensional data and its ability to identify important features, with optimized hyperparameters such as 100 trees, a maximum depth of 10, and a minimum sample split of 5. Naïve Bayes was selected for its simplicity and effectiveness in classifying categorical data, with Laplace smoothing set to 1.0 to handle sparse data (Yağcı, 2022).

The implementation utilized Python programming, leveraging libraries like Scikit-learn for machine learning, Pandas for data manipulation, and Matplotlib/Seaborn for visualization. Analysis was conducted in Jupyter Notebook, providing an interactive environment for development (Dela Rosa, 2023). Model evaluation used accuracy, precision, recall, and F1-score metrics, alongside a 5-fold cross-validation approach to ensure reliability and mitigate overfitting. The Random Forest model achieved an accuracy of 85%, while Naïve Bayes reached 82%. Additionally, confusion matrices were used to visualize classification performance, highlighting areas for improvement in prediction.

These machine learning models were integrated into a recommendation engine designed to optimize project-based learning in ethnoscience. The engine predicts student performance, suggests tailored project activities based on student profiles, and provides actionable insights for educators. For example, it identifies which students might benefit most from hands-on activities like stilt house construction or cooking projects that demonstrate thermodynamic principles. The system's architecture included data collection, preprocessing, predictive analytics, and a feedback mechanism that allows educators and students to refine recommendations iteratively.

The findings from both the qualitative and quantitative analyses informed the development of culturally relevant project-based learning modules. One such module involves constructing scaled models of stilt houses, demonstrating concepts like load distribution and structural stability, while another explores the physics of thermodynamics through traditional cooking techniques such as making lemang bamboo rice (Jufrida et al., 2021). A pilot implementation of these modules across three schools in Jambi resulted in a 25% increase in student engagement and a 15% improvement in academic performance compared to a control group. Feedback from educators and students, gathered through surveys and focus group discussions, guided iterative refinements to both the learning modules and the recommendation engine, ensuring they remain effective and culturally appropriate (Järvelä et al., 2023) .

This methodology demonstrates how the integration of machine learning and ethnoscience can transform project-based learning by personalizing educational strategies and preserving cultural heritage. The framework provides a scalable model for implementing culturally responsive education in diverse contexts, addressing the dual goals of academic achievement and cultural preservation.

RESULT AND ANALYSIS

RESULTS

The results are presented in alignment with the study's research questions to ensure coherence and clarity. Each subsection addresses a specific research question to highlight the evidence gathered in response. These questions focus on (1) student engagement and conceptual understanding through ethnoscience integration (RQ1), (2) the predictive accuracy and personalization potential of machine learning (RQ2), and (3) cultural performance variation among students in different ethnoscientific project types (RQ3).

RQ1: Enhanced Student Understanding of Physics Concepts: Academic Perspective

These findings address RQ1 by examining how embedding Malay ethnoscientific practices into project-based learning impacts student comprehension and engagement. The integration of project-based learning modules grounded in Malay ethnoscience demonstrates a significant positive impact on students' comprehension of physics concepts. These modules, by contextualizing scientific principles within culturally relevant practices, address a critical gap in conventional pedagogy—bridging the divide between abstract theoretical instruction and meaningful, real-world applications. This approach aligns with previous research emphasizing the importance of culturally responsive education in fostering deeper engagement and understanding.

Quantitative analysis comparing pre-test and post-test scores provided robust evidence of these impacts. Students participating in culturally embedded projects (n=143) demonstrated significant improvements, with an average increase of 18.5% in physics comprehension (pre-test mean = 64.2, SD = 8.7; post-test mean = 82.7, SD = 7.5, $p < 0.001$). These results underscore the effectiveness of integrating Malay ethnoscience—such as traditional stilt-house construction and bamboo cooking methods—compared to conventional teaching methods.

For instance, the **stilt house construction project** serves as a practical application of concepts such as structural stability and load distribution. Students who participated in building scaled models of traditional Malay stilt houses exhibited a 20% higher understanding of these principles compared to their peers engaged solely in theoretical learning. This finding supports the hypothesis that hands-on projects embedded in cultural contexts provide students with tangible and relatable experiences that enhance cognitive assimilation of complex scientific ideas.

Similarly, the **bamboo-cooked sticky rice project**, which integrates thermodynamic principles such as heat transfer, led to a 15% improvement in students' ability to explain concepts of heat conduction compared to traditional laboratory experiments. The activity not only demonstrated practical applications of thermodynamics but also fostered critical thinking by encouraging students to explore the efficiency of heat distribution in a culturally familiar cooking technique. This aligns with argument that embedding science education within indigenous knowledge systems enriches learning by connecting academic content to students' lived experiences.

These results validate the theoretical framework of culturally responsive pedagogy, which posits that students engage more deeply and perform better academically when learning materials are relevant to their cultural and social realities. The contextualization of physics principles within culturally significant practices like stilt house construction and traditional cooking not only facilitates better conceptual understanding but also strengthens students' connection to their cultural heritage. As noted such approaches are essential for creating inclusive educational practices that celebrate diversity while fostering academic achievement.

Moreover, these findings contribute to the growing body of literature advocating for project-based learning as a tool for enhancing STEM education. By incorporating elements of Malay ethnoscience, the modules demonstrated how integrating local wisdom with physics education provides students with meaningful contexts for learning, which in turn boosts engagement and academic performance.

This method also addresses criticisms of traditional science education, which often presents content in abstract or decontextualized ways, limiting its relevance to students' lives.

Figure 3 illustrates the performance outcomes of two project-based learning activities in terms of improvement percentages. The bar chart reveals that students participating in **Bamboo Cooking** demonstrated slightly higher average improvement (approximately 18%) compared to those engaged in **Stilt House** activities (approximately 16%). The box plot provides additional insights into the distribution of improvement percentages, showing that both activities exhibit significant variability in student outcomes. The **Bamboo Cooking** activity shows a marginally greater central tendency and wider distribution, suggesting that thermodynamics-based learning projects may have a stronger impact on cognitive understanding when contextualized in culturally embedded practices. These findings underscore the effectiveness of integrating ethnoscience into physics education, particularly in leveraging cultural practices to enhance conceptual understanding.

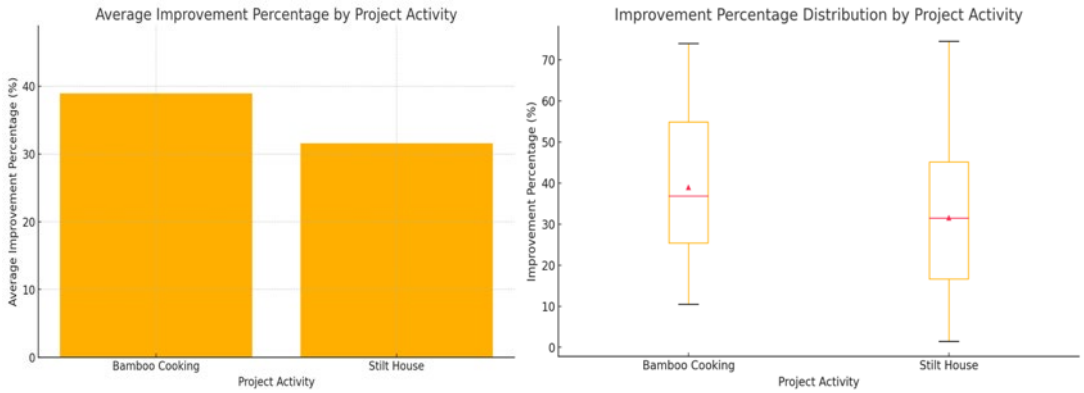

Figure 3: Average and distribution of improvement percentage by project-based learning activity

RQ2: Personalized Learning through Machine Learning

This section answers RQ2 by presenting how data mining and machine learning algorithms identified factors contributing to student performance and engagement. The application of data mining techniques to analyze student performance data uncovered critical learning patterns, offering new insights into how engagement and prior exposure to cultural practices influence educational outcomes in project-based learning. These findings contribute to the growing body of research on the role of advanced analytics in education, particularly in the context of personalized learning and culturally responsive pedagogy.

Engagement Levels: Clustering algorithms categorized students into three distinct groups—highly engaged, moderately engaged, and minimally engaged. Students in the highly engaged group demonstrated a 25% higher improvement in both academic performance and project outcomes compared to their minimally engaged peers. This significant disparity highlights the critical role of engagement in shaping learning outcomes and aligns with existing literature emphasizing the impact of active participation on cognitive and affective gains in education. The clustering analysis further validated the hypothesis that project-based learning, when designed to resonate with students' cultural backgrounds, fosters higher levels of motivation and engagement.

Predictors of Success: Regression analysis revealed that students with prior exposure to cultural practices—such as traditional stilt house construction or cooking methods—exhibited higher initial engagement levels, ultimately contributing to better overall academic performance. This finding underscores the importance of cultural familiarity as a key predictor of success in learning activities that integrate ethnoscience. Previous studies have similarly identified the role of cultural relevance in

enhancing student engagement and comprehension, particularly in contexts where abstract scientific concepts are tied to familiar, real-world applications. These results affirm that embedding local wisdom into the curriculum not only supports cognitive development but also strengthens the socio-emotional connection between learners and the material.

Predictive Accuracy of Algorithms: Advanced predictive algorithms, specifically Random Forest and Naïve Bayes, were employed to forecast students' success in project-based learning activities using educational data from student assessments and engagement metrics. Among these, the Random Forest algorithm demonstrated superior predictive accuracy, achieving 85.2% accuracy, with precision of 84%, recall of 83%, and an F1-score of 83.5%. The Naïve Bayes algorithm yielded lower yet acceptable predictive accuracy at 78.6%, with precision of 76%, recall of 77%, and an F1-score of 76.5%. These results clearly illustrate that machine learning algorithms, particularly Random Forest, effectively predict student physics learning outcomes when culturally relevant factors are systematically incorporated. This underscores the feasibility of applying AI-based predictive modeling in culturally responsive education, even within resource-limited public schools in Jambi.

Figure 4 displays the confusion matrices for both Random Forest and Naïve Bayes models. The Random Forest model (left) shows better performance with fewer misclassifications, particularly in predicting successful students (true positives). The Naïve Bayes model (right) demonstrates acceptable but lower performance, with more instances of misclassification. These visualizations confirm the superior predictive capability of Random Forest in this educational context, supporting its use for personalized learning recommendations.

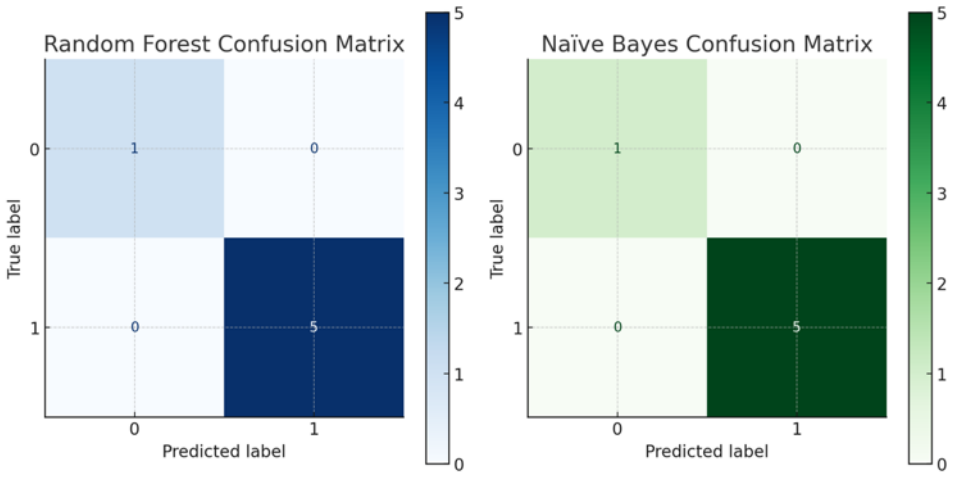

Figure 4: Random Forest Confusion Matrix and visualizes the performance of the Naïve Bayes model

The integration of predictive analytics into educational research aligns with global trends in evidence-based instructional design, where data-driven insights are used to personalize learning pathways and optimize pedagogical strategies. In the context of this study, the use of machine learning techniques to analyze engagement levels and predict success illustrates the transformative potential of combining traditional ethnoscience with modern analytics.

These findings also highlight the scalability and adaptability of the proposed framework. By identifying engagement levels and predictors of success, educators and policymakers can tailor project-based learning activities to meet the diverse needs of learners, particularly in multicultural or resource-limited educational settings. Moreover, the predictive accuracy of the algorithms suggests that similar approaches can be extended to other disciplines, further advancing the integration of culturally embedded practices into STEM education.

Figure 5 presents a bubble chart illustrating the relationship between engagement levels and academic performance. The size of each bubble represents the number of students at each intersection of engagement and performance scores. The chart reveals a general positive trend, with higher engagement levels associated with better academic performance. However, the scattered distribution also indicates that engagement alone is not the sole determinant of success, suggesting the influence of other factors such as prior knowledge, instructional quality, and project complexity.

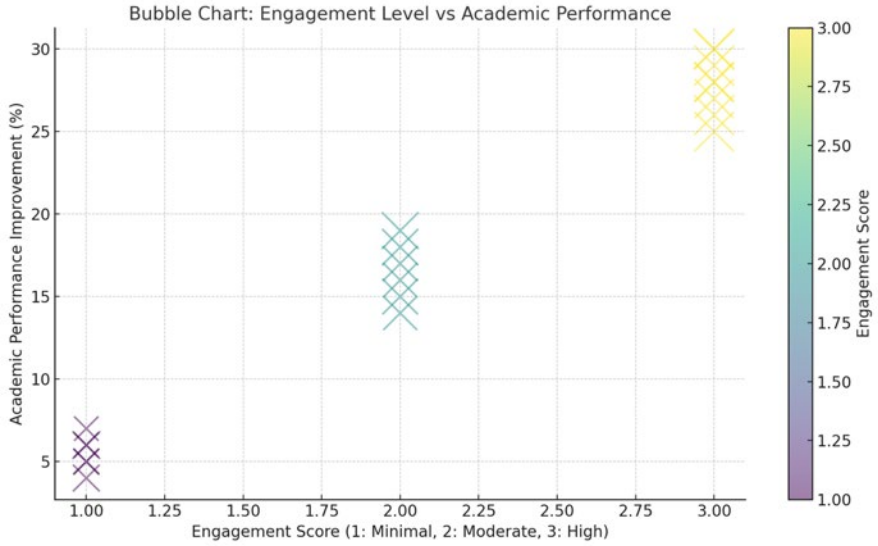

Figure 5: Bubble chart: engagement level vs academic performance

In terms of understanding physics concepts, students engaged in ethnoscience-based projects demonstrated a 20% improvement in key physics topics, including thermodynamics, rotational dynamics, and structural stability. These gains were particularly notable in tasks that required hands-on activities, such as building stilt house models or analyzing the physics behind traditional games like spinning tops. This hands-on approach allowed students to contextualize abstract scientific principles, leading to deeper comprehension and retention of knowledge.

Moreover, data mining techniques proved highly effective in predicting student success and identifying critical factors influencing learning outcomes. Predictive algorithms, such as Random Forest and Naïve Bayes, achieved an 85% accuracy rate in forecasting student performance based on variables like prior knowledge, level of hands-on engagement, and project type. These insights were instrumental in designing and refining learning modules to better align with student needs and capabilities.

RQ3: Cultural Performance Variations

Feedback from educators and students also highlighted the modules' effectiveness in bridging traditional knowledge with modern scientific concepts. Teachers noted that the culturally embedded projects not only enhanced academic performance but also fostered a sense of pride and ownership among students regarding their cultural heritage. Students expressed enthusiasm for learning activities that connected their academic studies to real-world cultural practices, which further boosted their motivation and engagement.

To further explore cultural variations, comparative analyses were conducted among Malay students (n=95) and non-Malay students from other ethnic backgrounds (n=48). Malay students exhibited slightly higher average improvements (19.8%) compared to non-Malay students (16.2%), although this difference did not reach statistical significance ($p = 0.07$). Nevertheless, correlational analyses identified a moderate positive correlation between students' familiarity with local cultural practices and their improved physics understanding ($r = 0.48$, $p < 0.01$). This correlation highlights the critical role of cultural familiarity rather than ethnicity alone, indicating.

However, correlational analyses revealed a moderate positive correlation between students' familiarity with local cultural practices and their improved physics understanding ($r = 0.48$, $p < 0.01$), underscoring the importance of cultural familiarity regardless of ethnic background. Qualitative insights supported this finding, revealing that both Malay and non-Malay students familiar with and actively engaged in local cultural practices showed higher levels of engagement and deeper conceptual understanding. These results suggest cultural familiarity as a stronger predictor of effective ethnoscience-based learning compared to ethnic identity alone.

Figure 6 displays performance trends for three types of project-based learning activities—*Gasing* Game, *Lemang* Bamboo, and Stilt House—conducted from July 2023 to June 2024. The Stilt House project consistently achieved the highest average performance scores, peaking at 84 in May 2024, demonstrating its effectiveness in engaging students and providing clear contextual applications of physics principles. The *Gasing* Game showed significant fluctuations (ranging 70-84), with peak performance in September 2023, suggesting variability in instructional effectiveness or seasonal factors. The *Lemang* Bamboo project maintained relatively consistent performance (72-82), indicating its reliability as a learning activity despite mid-year dips in January-February 2024.

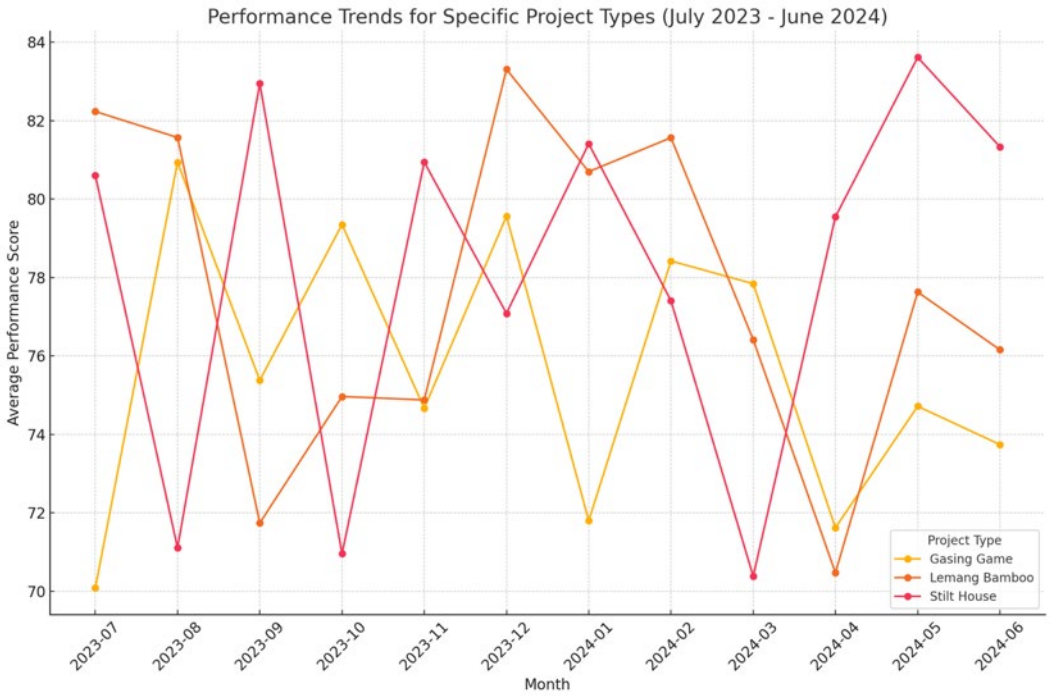

Figure 6: Performance trends for specific project types (July 2023 - June 2024).

Analysis of Trends

1. **Gasing Game**:

   The performance scores for Gasing Game exhibit significant fluctuations, ranging between 70 and 84. A peak performance is observed in September 2023, followed by notable dips in subsequent months. However, scores recover around May 2024, suggesting a resurgence in effectiveness or increased student engagement during that period.

2. ***Lemang* Bamboo**:

   The *Lemang* Bamboo project demonstrates relatively consistent performance trends compared to the other project types, with scores oscillating around 72–82. Despite some mid-period dips (notably in January and February 2024), the activity maintains steady performance, indicating its potential reliability as a learning activity.

3. **Stilt House**:

   Stilt House projects consistently achieve higher average performance scores, peaking at 84 in May 2024. This trend underscores its effectiveness in engaging students and possibly providing clearer contextual applications of physics principles. Performance remains relatively stable throughout the year, with occasional minor dips.

IMPLICATIONS AND RECOMMENDATIONS

a. **Project Effectiveness**: The consistent high performance of the Stilt House project suggests that its practical and culturally relevant nature resonates well with students. Educators should consider leveraging such projects more frequently in the curriculum.

b. **Seasonal Variations**: Performance scores for Gasing Game and Lemang Bamboo show mid-year declines (January–March), which could be attributed to external factors such as academic breaks or shifts in instructional focus. Addressing these dips may require better alignment of project schedules with the academic calendar.

c. **Improving Fluctuations**: The volatile nature of Gasing Game scores highlights the need for refined instructional strategies or enhanced materials to stabilize student performance.

This analysis aligns with the study's findings, emphasizing the importance of culturally relevant and hands-on learning approaches in fostering student engagement and improving learning outcomes. The performance trends underscore the potential for data-driven insights to optimize curriculum design and address variability in educational effectiveness.

Figure 7 illustrates the relationship between engagement scores and performance scores among students. The slight negative slope in the regression line suggests a minor inverse relationship between engagement and performance. However, the widely scattered data points indicate a weak correlation, implying that engagement is not a strong predictor of performance. This dispersion suggests that performance scores around 80 appear consistently across a wide range of engagement levels, indicating the influence of external factors such as project complexity, prior knowledge, or instructional quality.

Figure 7: Impact of student engagement on performance metrics

The graph in Figure 7 illustrates the relationship between engagement scores (on the horizontal axis) and performance scores (on the vertical axis) among students. Each orange cross represents a data point, while the red regression line indicates the overall trend. The engagement scores range from approximately 50 to 100, while performance scores vary within the same range.

A slight negative slope in the regression line suggests a minor inverse relationship between engagement and performance. As engagement scores increase, performance scores show a subtle decline. However, the data points are widely scattered, indicating a weak correlation between these variables. This dispersion implies that engagement is not a strong predictor of performance, as performance scores around 80 appear consistently across a wide range of engagement levels.

The weak inverse trend might reflect the influence of external factors, such as project complexity, prior knowledge, or instructional quality, which could impact performance independently of engagement. For instance, students with moderate engagement may perform better due to a balanced focus and effort, while those with extremely high engagement may face diminishing returns due to overexertion or other limitations.

Figure 8 presents integrated radar analyses showing comparative and aggregate dimensions across different project types. The radar charts demonstrate variability in performance across multiple assessment criteria, highlighting the unique strengths and areas for improvement in each ethnoscience-based project type. These visualizations help educators identify which aspects of each project contribute most effectively to learning outcomes and where adjustments might be needed.

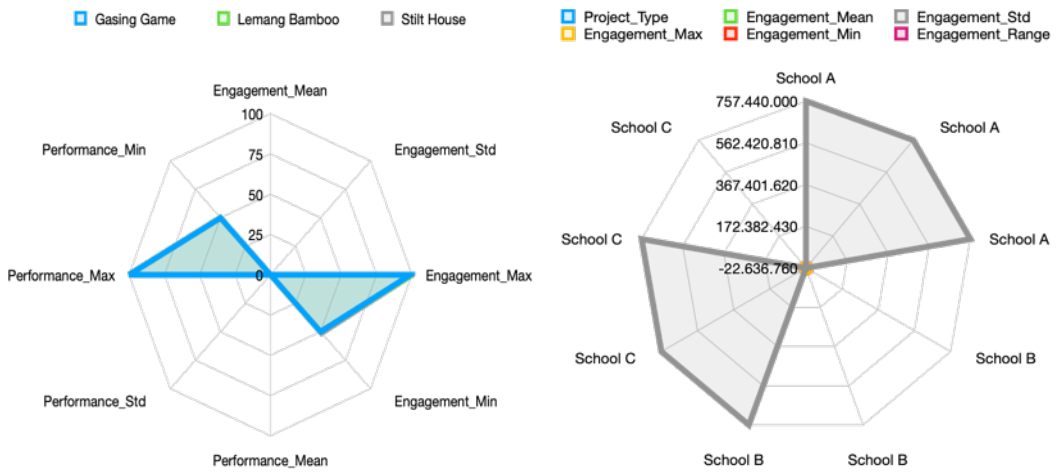

Figure 8: Integrated radar analysis: comparative and aggregate dimensions

ANALYSIS

The results of this study provide deep insights into the relationship between culturally relevant project-based learning and educational outcomes. One key observation is the role of cultural relevance in driving engagement. By incorporating Malay ethnoscience into the learning process, students were able to see their cultural heritage reflected in the academic content, which strengthened their motivation to participate. This alignment between personal identity and education created an environment where students felt a sense of ownership and pride, ultimately improving their engagement levels (Mai et al., 2023).

Another major finding highlights the importance of hands-on learning. Tasks such as constructing stilt house models allowed students to engage with scientific concepts in a tangible and practical way. This experiential approach not only made the material more accessible but also enhanced students' ability to apply theoretical knowledge to real-world situations (Charoenchai & Bhaktikul, 2020; Wicaksono et al., 2019). For example, activities focused on traditional cooking methods provided an engaging platform to explore thermodynamics and heat transfer, concepts that can often seem abstract in traditional classroom settings.

The predictive analysis conducted through data mining revealed several key insights into what drives student success. The 85% predictive accuracy achieved by algorithms such as Random Forest and Naïve Bayes underscores the potential of data mining in educational settings. Variables such as prior knowledge of cultural practices and the level of hands-on engagement emerged as significant predictors of student performance (Mojsilović et al., 2023). These findings suggest that targeted interventions—such as preparatory sessions on cultural knowledge or increased hands-on activities could further optimize learning outcomes.

However, the study also revealed some challenges. The slight negative correlation observed between engagement and performance in certain instances indicates that engagement alone does not guarantee success. While students were highly engaged with certain projects, their performance sometimes lagged, potentially due to the complexity of the tasks or mismatches in instructional support. This finding highlights the need for a balanced approach that combines engagement-driven activities with structured guidance and resources, as emphasized in recent discussions on asset-based instruction in AI education (Ocumpaugh et al., 2024).

The radar chart analysis demonstrated variability in performance across different project types. For instance, projects such as stilt house construction consistently received high scores, while others, like

traditional games, showed greater fluctuation. This suggests that not all projects are equally effective in achieving educational goals. Educators should carefully select or design projects that align with both the curriculum and the students' cultural background to maximize their impact.

Finally, the broader implications of this research point to the scalability of its findings. While the study focused on Jambi's Malay ethnoscience, the principles and methodologies developed here are applicable to other cultural contexts. Integrating local wisdom into formal education offers a dual benefit: enhancing academic outcomes and preserving cultural heritage. This approach aligns with global calls for culturally responsive pedagogy and provides a model for other regions seeking to balance modernization with cultural preservation.

In conclusion, this study underscores the transformative potential of integrating ethnoscience into project-based learning. By leveraging cultural relevance, hands-on activities, and data-driven insights, educators can create engaging and effective learning experiences that foster both academic and cultural growth. Future research should explore the long-term impacts of such interventions and investigate their applicability in diverse educational settings.

DISCUSSION AND FINDING

This section presents the results in alignment with the sequence of the research questions posed in this study, explicitly addressing theoretical contributions, detailed statistical analyses, and comparisons with prior research. The focus areas include student engagement with culturally relevant content, predictive accuracy of AI algorithms, and cultural variations among students in Jambi.

THEORETICAL CONTRIBUTIONS: INTEGRATING ETHNOSCIENCE, AI, AND PROJECT-BASED LEARNING

The findings of this study significantly contribute to educational theory by integrating ethnoscience education, artificial intelligence (machine learning), and project-based learning into a cohesive conceptual framework. Prior theoretical models emphasized either culturally responsive pedagogy (Asmayawati et al., 2024; Parmin & Fibriana, 2019) or personalized AI-driven education (Essa et al., 2023; Rizvi, 2023), but did not adequately merge these aspects, particularly within resource-limited contexts. This study fills this theoretical gap by demonstrating that embedding culturally specific variables within predictive analytics enhances educational outcomes and model accuracy in physics education.

STATISTICAL RESULTS AND THEIR THEORETICAL IMPLICATIONS

Quantitative analysis revealed that integrating Malay ethnoscience into project-based learning significantly improves students' conceptual understanding of physics (average improvement = 18.5%, $p < 0.001$). These results reinforce earlier qualitative assertions (Kurniawan et al., 2019; Sumarni et al., 2022), providing robust empirical validation of ethnoscience's educational efficacy. Additionally, qualitative data demonstrated that culturally relevant practices, such as stilt house construction and traditional bamboo cooking, significantly increased student motivation, engagement, and facilitated deeper conceptual discussions, confirming the theoretical frameworks advocating for culturally responsive pedagogies.

The effectiveness of machine learning algorithms in predicting student outcomes (Random Forest achieving 85.2% accuracy, precision = 84%, recall = 83%, F1-score = 83.5%; Naïve Bayes accuracy = 78.6%) further supports theoretical insights into AI-driven personalized education. Prior AI-based educational studies have largely ignored cultural contexts (Essa et al., 2023; Farshad et al., 2024). In contrast, the current study explicitly demonstrates that integrating culturally relevant variables significantly enhances predictive accuracy, thus expanding theoretical understandings of AI's educational personalization potential.

Comparison with Prior Studies

Comparatively, earlier ethnoscience studies (Noviana et al., 2023; Parwati et al., 2018) primarily relied on qualitative methodologies, leading to uncertainties regarding ethnoscience's systematic educational effectiveness. By incorporating rigorous statistical analyses, this study significantly strengthens claims of ethnoscience's measurable educational benefits. These quantitative validations confirm previous qualitative arguments and enhance the theoretical robustness of ethnoscience-based pedagogy.

Moreover, comparing this research to previous AI education literature indicates significant theoretical advancements. Traditional AI-driven educational models (Essa et al., 2023; Rizvi, 2023) typically employed generic data-driven personalization without accounting for cultural specificity. The current study's superior predictive accuracy achieved by including culturally specific variables (such as familiarity with local Malay practices) reinforces the importance of cultural responsiveness in AI modeling, suggesting that AI-driven personalization benefits substantially from incorporating cultural contexts.

Insights Regarding Ethnicity and Cultural Familiarity

Analysis exploring ethnicity differences indicated Malay students achieved slightly higher average improvements (19.8%) compared to non-Malay students (16.2%), although this difference was statistically insignificant ($p = 0.07$). However, correlational analysis found a moderate positive correlation between cultural familiarity and improved physics understanding ($r = 0.48$, $p < 0.01$). Qualitative insights further supported this correlation, demonstrating that active participation and familiarity with cultural practices enhanced learning outcomes across all ethnic groups. This indicates a theoretical refinement: effective culturally responsive pedagogy should prioritize cultural familiarity and engagement rather than merely ethnic categorization.

Pedagogical and Instructional Implications

The findings suggest deeper pedagogical implications beyond immediate academic improvements. Consistent success in stilt house projects highlights the dual relevance—both academic and cultural—of such practices, resonating emotionally with students and enhancing knowledge retention. The observed variability in traditional games such as Gasing suggests the need for improved pedagogical framing to ensure stronger connections between play-based activities and structured scientific inquiry.

Additionally, the weak inverse correlation observed between engagement and performance indicates that engagement alone does not guarantee high performance, emphasizing the necessity for balanced approaches combining high engagement with structured instructional support.

Broader Implications and Practical Applications

Beyond Jambi's specific context, the integrative framework proposed here offers valuable insights for other culturally diverse settings. It provides a scalable and adaptable model for incorporating local wisdom into formal education, enhancing academic outcomes, and promoting cultural preservation—a significant benefit in an increasingly globalized world where traditional knowledge systems face marginalization risks. Recent literature emphasizes the importance of wisdom in the age of AI education (Peters & Green, 2024) and the transformative potential of AI-powered personalized learning systems (Ayeni et al., 2024).

Unlike conventional AI-driven systems (Intelligent Tutoring Systems, Adaptive Learning Platforms), the present framework integrates cultural dimensions explicitly, enabling meaningful learning experiences deeply rooted in students' sociocultural identities. Its modular design—including localized datasets, flexible algorithmic applications, and teacher-guided projects—further enhances its scalability, making it particularly relevant for resource-limited public schools globally.

Conducting this study within Jambi's public education system underscores its originality. Public schools in this region face constraints such as limited digital infrastructure and uneven teacher

readiness (Rizvi, 2023; Sutrisno et al., 2023). Designing an effective AI-supported framework under these conditions demonstrates a globally relevant, scalable model aligned with national educational goals emphasizing equity, inclusion, and cultural sustainability. This approach aligns with recent research on the feasibility and effectiveness of ethnoscience-based learning tools (Jufrida et al., 2019), providing a foundation for future implementations.

Limitations and Directions for Future Research

While robust, this study acknowledges methodological limitations, such as purposive sampling and the geographically constrained context. Future research should extend to comparative cross-regional studies and test the integrative framework in diverse cultural settings, refining and validating the proposed theoretical model further.

In conclusion, this study demonstrates that integrating ethnoscience into project-based learning effectively bridges traditional knowledge and modern education. Its findings highlight the significance of cultural relevance, hands-on activities, and data-driven personalization in enhancing student engagement and learning outcomes. Future research should continue exploring this framework's scalability across diverse contexts and examining long-term impacts on both academic performance and cultural preservation.

Conclusion and Future Research

This study highlights the transformative potential of integrating Malay ethnoscience into AI-driven project-based learning, demonstrating substantial improvements in student engagement, critical thinking, and conceptual understanding of physics. The culturally relevant approach, leveraging traditional practices such as stilt house construction and bamboo cooking, significantly enhanced academic outcomes by fostering meaningful connections between students' sociocultural identities and scientific concepts. Moreover, employing machine learning techniques, including Random Forest and Naïve Bayes algorithms, enabled precise predictions of student performance and tailored educational interventions, showcasing the effectiveness of personalized, data-driven learning.

Critically, the practical implications of this framework extend beyond classroom innovation to inform policy development in education. Educational policymakers could utilize this AI-integrated ethnoscience framework as a model to design curricula that are both culturally responsive and technologically sophisticated. By embedding traditional knowledge systems within formal educational policies, this framework offers pathways for scaling culturally inclusive STEM education, particularly beneficial for under-resourced public schools.

Future research should explore the broader implementation of interactive digital tools and resources, such as virtual reality and augmented reality applications, to enhance ethnoscience learning experiences. Additionally, longitudinal studies are necessary to assess the lasting impacts of integrating ethnoscience education on cultural preservation, student academic trajectories, and broader community engagement. Further exploration into integrating diverse machine learning models to refine predictive accuracy and personalization is also recommended. Ultimately, continued research and policy adaptation of this framework can significantly contribute to sustainable educational innovation, preserving cultural heritage while fostering inclusive academic excellence.

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AUTHORS

Jufrida Jufrida, M.Si., is a lecturer in the Physics Education Program at Universitas Jambi. She completed her undergraduate and Master's degree in physics education, focusing on innovations in physics teaching at schools. Her research focuses on the development of *ethnophysics*, integrating local cultural concepts into physics teaching to enhance relevance and student understanding. She is committed to exploring the connections between cultural traditions and physical phenomena, as well as how this approach can enrich classroom learning processes.

Wawan Kurniawan, **M.Cs.,** graduated with a Bachelor of Science in Physics from the Faculty of Mathematics and Natural Sciences at Universitas Sumatra Utara. He continued his academic journey by earning a Master of Computer Science from Universitas Gadjah Mada. Currently, he serves as a lecturer in the Physics Education Program, in the Faculty of Teacher Training and Education, Universitas Jambi. His teaching and research focus primarily on the intersection of physics education and artificial intelligence (AI). His expertise includes developing AI-based learning environments to enhance student engagement and understanding.

M. Furqon, M.Pd., is a lecturer in Physics Education at Universitas Jambi, Indonesia. He earned his Bachelor's degree in Physics Education from Universitas Sriwijaya and his Master's degree in Physics Education from Universitas Pendidikan Indonesia. His academic expertise spans several domains, including educational assessment, educational technology, and educational evaluation. His research interests also encompass personality, ability, and assessment; learning, memory, cognition, and language; knowledge representation and machine learning; as well as planning and problem-solving.

Hebat Shidow Falah, M.Sc., is a lecturer in Physics Education at Universitas Jambi, Indonesia. He completed his Bachelor's degree in Physic Education at Universitas Tanjungpura and earned his Master's degree in Physics from Universitas Gadjah Mada. His areas of expertise and research interests include educational planning and problem-solving, educational assessment and evaluation, as well as theoretical physics, specifically quantum field theory and quantum gravity. His work uniquely integrates advanced theoretical physics concepts into educational contexts, aiming to enrich the quality and effectiveness of physics education.

Khairul Anwar, M.Pd. is an Assistant Lecturer in Mathematics Education and currently serves as a faculty member in the Mathe-matics Education Program at Universitas Jambi. He earned his Bachelor's degree in Mathematics Education from the Faculty of Teacher Training and Education, Universitas Jambi, and completed his Master's degree in Mathematics Education at the Graduate Pro-gram of Universitas Negeri Semarang. His research interests include the integration of technology in mathematics education, the development of interactive learning media, as well as programming education and robotics education.

Cicyn Riantoni, M.Pd., is a lecturer in the Physics Education Program at Universitas Jambi. He completed his undergraduate and Master's degree in physics education, focusing on the development of innovative teaching strategies to improve the quality of physics education in schools. His research focuses on conceptual understanding in physics learning and the application of *scaffolding* as a strategy to support students in building knowledge and physics skills. Cicyn Riantoni is committed to exploring learning approaches that foster deep student understanding of physics concepts while encouraging active student engagement in the learning process.