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Integrating PjBL-STEAM with Balinese *Meru* Architecture to Enhance Students' Mathematical Conceptual Understanding

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Abstract

Traditional mathematics education often struggles to connect abstract concepts with real-world relevance, particularly in geometry, where students find it challenging to visualize spatial relationships and applications. This study addresses this gap by integrating Balinese *Meru* temple architecture into a Project-Based Learning (PjBL) model infused with STEAM (Science, Technology, Engineering, Arts, Mathematics) to improve students' conceptual understanding of geometry. A quasi-experimental post-test-only control group design was employed, involving 63 eighth-grade students (31 in the experimental group and 32 in the control group) at SMP Negeri 1 Singaraja, Indonesia. The experimental group participated in PjBL-STEAM activities exploring *Meru* temple geometry, while the control group received conventional instruction. Data were collected through post-tests assessing conceptual understanding, analyzed using independent sample t-tests, and supplemented with observations and interviews. Results indicated that the PjBL-STEAM approach incorporating *Meru* temple geometry significantly outperformed conventional methods, with the experimental group achieving a higher mean score (81.84 vs. 73.05, $p = 0.024$). Students demonstrated an improved ability to articulate geometric concepts, identify relevant examples, and apply their knowledge within cultural contexts. The study concludes that culturally contextualized PjBL-STEAM enhances conceptual mastery by bridging abstract mathematics with tangible cultural artifacts, suggesting its potential for broader application in other educational areas.

Keywords: PjBL-STEAM, Ethnomathematics, Conceptual Understanding, *Meru* Bali, Geometry Education

INTRODUCTION

Mathematics education faces persistent challenges in fostering meaningful conceptual understanding, specifically in geometry, where students often perceive the subject as abstract and disconnected from real-world settings (Gülburnu & Yildirim, 2021; Suarsana & Mahayukti, 2013). In Indonesia, this issue is eescalated by a practice of rote learning and teacher-centered methods, limiting students' ability to apply mathematical concepts (Arisetyawan, 2015; Putri, 2021). For instance, (Abi, 2017) found that 65% of Indonesian students struggle with geometry due to its abstract presentation, reinforcing the need for innovative, culturally grounded teaching strategies.

Accordingly, researchers advocate for interdisciplinary and project-based approaches that integrate local cultural contexts into mathematics education. Degeng et al. (2021) several evidences (Chistyakov et al., 2023; Han et al., 2015; Lou et al., 2012; Lu et al., 2022; Zayyinah et al., 2022) argue that STEAM (Science, Technology, Engineering, Arts, Mathematics) frameworks, combined with Project-Based Learning (PjBL), can enhance conceptual understanding by fostering creativity and real-world problem-solving. In the same manner, Wardanaa et al. (2021) demonstrate that ethnomathematics linking mathematical concepts to cultural artifacts, improves student engagement and comprehension. These studies show the potential of culturally responsive pedagogy but reveal a gap in empirical evidence on its effectiveness in geometry education, particularly in Indonesia.

Previous research has explored PjBL-STEAM and ethnomathematics separately, yet few studies combine these approaches to address geometry learning challenges. For example, Yanti et al. (2021) showed that PjBL-STEAM improved problem-solving skills and conceptual, while Putri (2021) confirmed that ethnomathematics based on *Meru* temple architecture increased student motivation. However, neither study examined the synergistic effect of these methodologies on conceptual understanding. This research bridges that gap by employing the PjBL-STEAM model contextualized with *Meru* Bali's geometric principles, grounded in constructivist theory and the NCTM (Saleh Haji, 2019) standards for conceptual learning. The novelty lies in its dual focus: (1) leveraging *Meru*'s architectural geometry (e.g., proportional *tri angga* structure, *asta kosala-kosali* measurements) as a cultural scaffold for abstract concepts, and (2) empirically testing the model's impact through quasi-experimental design.

This study focuses on evaluating how the PjBL-STEAM *Meru* Bali model influences eighth-grade students' ability to understand, apply, and communicate geometric concepts. It addresses the research question: Does the PjBL-STEAM model using *Meru* Bali's cultural context significantly improve students' mathematical conceptual understanding compared to conventional methods? By answering this, the study aims to contribute a replicable framework for integrating cultural heritage into mathematics education while addressing global calls for contextualized learning.

METHODS

This study employed a quasi-experimental post-test-only control group design to investigate the effectiveness of the PjBL-STEAM *Meru* Bali model in enhancing students' mathematical conceptual understanding. The research involved 63 eighth-grade students (31 in the experimental group and 32 in the control group) from SMP Negeri 1 Singaraja, Indonesia, selected through cluster random sampling to ensure comparable academic levels. The experimental group participated using the PjBL-STEAM model that integrated the geometry of Balinese *Meru* temples, while the control group received conventional instruction on the same topics. Data were collected through a validated post-test assessing three aspects of conceptual understanding based on NCTM (Muhamad, 2016; Saleh Haji, 2019; Sri & Asih, 2017; Umbara et al., 2021) standards: restating concepts, identifying examples/non-examples, and applying concepts to real-world problems. Classroom observations documented student engagement during activities, and semi-structured interviews with students explored their perceptions of the cultural context. Quantitative data were analyzed using independent sample t-tests after confirming normality and homogeneity of variance. The study was implemented over an eight-week period (January, 30th -March, 1st 2023), comprising two weeks for instrument preparation, four weeks of instructional intervention, one week for post-testing and interviews, and a final week for comprehensive data analysis. Ethical standards were maintained in the research through obtaining the necessary permissions and participant anonymity throughout the research process.

RESULTS

The researcher systematically integrated Bali's *Meru* architecture into mathematics instruction through a Project-Based Learning (PjBL) model enriched with STEAM (Science, Technology, Engineering, Art, Mathematics) principles. Students first explored the *Meru*'s tripartite structure (*bebaturan*, *pengawak*, and *raab*) before they studied its proportional system (*kekuub*) which dictates ratios. They applied these ratios to calculate dimensions for scale models, translating traditional Balinese units (*musti*, *hasta*) into metric equivalents using formulas derived from lontar manuscripts (e.g., iterative roof-tier equations like 2(9p−(p+q)i). Guided by the STEAM framework, students designed 3D *Meru* miniatures, integrating geometric principle, engineering concepts, and artistic elements. This practical approach brought theoretical mathematics into the domain of Bali's architecture, so students could deal with real issues such as how to optimize a 45° roof slope for wind resistance, all while fulfilling curriculum requirements in spatial awareness and measurement. Figure 1 and 2 below sequentially illustrate the architectural design of a *Meru* and showcase the *sineb-lambang* system.

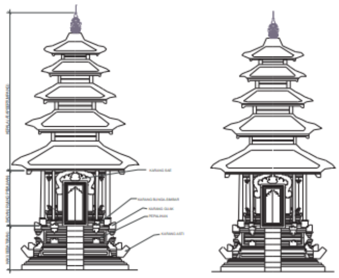

Figure 1. Meru Structure Design

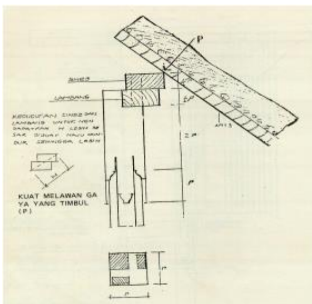

Figure 2. *Sineb-lambang* System in *Meru* Design

The quantitative data analysis began with testing the fundamental assumptions for parametric analysis. The Kolmogorov-Smirnov test results (Experimental: $p = 0.084$; Control: $p = 0.087$) confirmed that both groups' scores were normally distributed, while Levene's test for equality of variances ($p = 0.377$) indicated that the homogeneity assumption was satisfied. With these parametric assumptions met, an independent samples t-test was conducted to examine the hypothesis, revealing that students in the PjBL-STEAM *Meru* Bali experimental group ($M = 81.84$, $SD = 13.42$) demonstrated significantly higher conceptual understanding scores compared to the control group ($M = 73.05$, $SD = 16.53$), with $p = 0.024$. These results provide empirical support for the effectiveness of the culturally-integrated PjBL-STEAM approach in enhancing students' mathematical understanding, while the assumption tests validate the appropriateness of the statistical methods employed in the analysis. Data analysis summarize on table below.

Table. 1 Quantitative Results

Test	Experiment	Control	Result
Kolmogorov-Smirnov test	$p = 0.084$	$p = 0.097$	Normally Distributed
Levene's tes	$p = 0.377$		Homogenic
Independent T-test	$M = 81.84$	$M = 73.05$	demonstrated significantly higher
	$p < 0.05$		

Notably, the study documented challenges in translating traditional Balinese units (*musti, hasta*) into metric equivalents during model construction. Approximately 10% of experimental group students initially miscalculated roof-tier ratios (e.g., misapplying the formula $2(9p-(p+q)i)$ due to confusion between base-4 Balinese numbering and decimal systems). These anomalies were evident in preliminary design submissions and observation logs. While these difficulties did not negate the overall positive outcomes, they underscored the need for explicit instructional support in cross-system unit conversions.

These combined results demonstrate that the PjBL-STEAM *Meru* Bali approach not only improved test scores but also fostered more positive attitudes toward mathematics learning while maintaining cultural connections. The moderate effect size suggests practical significance beyond statistical significance, particularly in helping students bridge abstract concepts with concrete cultural examples.

DISCUSSION

The findings of this study offer compelling evidence that the PjBL-STEAM *Meru* Bali model has a large impact on increasing students' mathematical conceptual understanding, addressing the critical gap between abstract geometry and cultural relevance identified in the Introduction. These results align with but substantially extend previous research in three keys. To begin with, Degeng et al. (2021) and Wardanaa et al. (2021) established the individual benefits of STEAM and ethnomathematics approaches respectively, our integrated model demonstrates their synergistic effect through both quantitative gains ($p = 0.024$) and qualitative insights into student engagement. Second, the study validates sociocultural theory in a novel context, showing how *Meru* architecture serves as an effective cultural tool for mediating geometric concepts, particularly in spatial visualization and application where conventional instruction often fails (Gülburnu & Yildirim, 2021). Third, the identified challenges in unit conversion between traditional and metric measurements reveal an important nuance not captured in previous ethnomathematics studies (Lou et al., 2012; Nuh & Dardiri, 2017; Putri, 2021; Saraswandewi et al., 2019; Suharta et al., 2017; Widyantini, 2019), suggesting the need for targeted scaffolding in culturally-grounded mathematics instruction. The primary contribution of this research is the demonstration that STEM educational models can be strengthened by profound cultural infusion, rather than weakened. This forms a replicable pattern that upholds mathematical rigor while simultaneously increasing relevance and engagement. Three primary limitations warrant consideration. First, the quasi-experimental design, while practical for classroom settings, limits generalizability due to the absence of random assignment at the individual level. Second, the 8-week intervention period may have been insufficient to assess long-term retention of concepts, particularly for complex geometric principles. Third, reliance on a single Indonesian school context (SMP Negeri 1 Singaraja) restricts cross-cultural applicability, as student responses may reflect local cultural familiarity with Meru architecture. These limitations suggest caution when interpreting the results and indicate opportunities for future research with expanded timelines and more diverse participant pools.

CONCLUSION

This study provides compelling evidence that the PjBL-STEAM Meru Bali model significantly enhances students' mathematical conceptual understanding compared to conventional teaching methods, effectively addressing the research question posed. The integration of Balinese temple architecture into geometry instruction through project-based learning and STEAM principles not only improved test scores but also fostered deeper engagement and appreciation for the cultural relevance of mathematics. The findings validate the theoretical premise that culturally contextualized learning serves as a powerful mediator for abstract concepts, particularly in geometry education, where students traditionally struggle with visualization and application. While the quasi-experimental design and single-school sample of the study present limitations in generalizability, the robust effect size and consistent qualitative evidence suggest meaningful educational implications. The results advocate for curriculum designs that thoughtfully incorporate local cultural artifacts as pedagogical tools, especially in mathematics education, where mastery of abstract concepts remains challenging. Future research should explore the model's adaptability across diverse cultural contexts and its longitudinal impact on mathematical reasoning skills. This study presents an empirically grounded solution to bridging the gaps between formal mathematics instruction and students' lived cultural experiences, offering a replicable approach to making mathematical learning both meaningful and rigorous.

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