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Enhancing students' mathematical representation profiles through Sekaten tradition-integrated e-worked examples

Reny Afifah, Supahar, and Ayu Mar'ati Barokatun Ni'mah

Departemen of Physics Education, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia

Email: renyafifah.2024@student.uny.ac.id

Abstract

Low student proficiency in transforming physical phenomena into symbolic models often stems from overly abstract instruction and a lack of connection to local contexts. This study aims to evaluate the effectiveness of e-worked example media integrated with Sekaten local wisdom in enhancing students' mathematical representation profiles. Using an R&D approach with the ADDIE model, this quasi-experimental study employed a non-equivalent control group design involving 108 students. Data were analyzed using Item Response Theory and N-gain scores. Findings indicate a significant improvement in the experimental class, with an average N-gain of 75% and 89% of students reaching high-category proficiency. This significantly outperformed the control group, which showed only a 49% improvement. The integration of cultural context and structured cognitive guidance successfully bridged the gap between abstract physics and mathematical modeling while reducing cognitive load. These results show that culturally responsive digital tools are practical frameworks for contextualizing physics and improving the precision of symbolic representation.

Keywords: Mathematical representation, Local wisdom, Sekaten, Worked example

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I. Introduction

Achieving proficiency in high-level cognitive skills has become a primary requirement for students navigating the demands of 21st-century education [1]–[3], with mathematical representation standing out as one of the most essential competencies [4]. Mathematical representation serves as a fundamental process that enables students to systematically organize, record, and communicate their scientific thinking [5]–[8]. Within physics, specifically in quantities and measurements, this ability is vital for converting physical phenomena into structured models, diagrams, or symbolic notations [9], [10]. However, empirical evidence indicates that many students still encounter significant difficulties when translating conceptual problems into accurate mathematical forms, which often leads to systemic errors in data interpretation [10], [11]. Therefore, mastering these representational skills is indispensable for students to achieve a comprehensive understanding of complex physical laws.

Efforts to overcome these pedagogical hurdles have led researchers to explore various instructional strategies. For instance, the application of the REACT strategy, supported by GeoGebra, has demonstrated potential to strengthen representational capabilities [12]. Additionally, Android-based platforms have proven effective in enhancing student engagement while clarifying abstract concepts [13]. Previous studies also suggest that embedding local wisdom into digital tools, such as mobile comics, can significantly enhance students' critical thinking by offering a familiar context [14]. These diverse approaches emphasize that integrating technology and contextual learning is key to making physics more accessible and engaging for modern learners.

Innovative learning media development is currently shifting its focus beyond mere digitalization toward optimizing cognitive load during the problem-solving process. Systematically designed e-worked examples provide a framework where students can observe step-by-step procedures, effectively building the mental schemas necessary to grasp the mathematical logic behind physical phenomena [15], [16]. By incorporating cultural elements like the Sekaten tradition, these tools function as both cognitive scaffolds and sociocultural bridges that increase the relevance of the curriculum [17]–[19]. The synergy between structured guidance and cultural familiarity is thus a strategic necessity in facilitating the transition from abstract theory to practical mathematical application [20], [21]. Consequently, an integrated approach that respects local values while utilizing digital efficiency can create a more holistic learning environment.

Despite these advancements, a significant research gap persists regarding the integration of procedural guidance and cultural context. Most existing studies on mathematical representation in physics focus on general problem-solving [17], [22] or the use of simulations without providing structured cognitive scaffolds [23]. There is a notable lack of research specifically investigating e-worked examples of digital tools providing step-by-step demonstrations integrated with cultural heritage. The novelty of this study lies in the synergistic integration of the Sekaten tradition, a Javanese cultural event rich in measurement patterns, into a dynamic e-worked example platform. This integration is designed to bridge the gap between abstract physics concepts and students' cultural reality by providing an intuitive model for developing representational profiles. This study provides an explicit contribution to the field of physics education by establishing contextual learning within digital learning environments. Methodologically, it demonstrates how integrating local wisdom can serve as a cognitive scaffold to reduce students' intrinsic cognitive load. Furthermore, this research offers a practical blueprint for curriculum developers in designing technology-based materials that enhance mathematical precision while preserving cultural identity, particularly the Sekaten tradition. Therefore, this study aims to evaluate the effectiveness of this approach by addressing the following research questions: (1) Is there a significant improvement in students' mathematical representation profiles after the intervention? (2) How do the results differ based on student characteristics before and after the treatment?

II. Methods

This research follows the Research and Development (R&D) methodology, specifically utilizing the ADDIE model developed by [23]. The model encompasses five critical stages: analysis, design, development, implementation, and evaluation, providing a comprehensive roadmap for the study.

Analysis

The initial analysis phase aims to identify fundamental issues within the instructional process through a multifaceted approach. This includes a performance analysis to determine the necessity of developing physics e-worked examples integrated with the local wisdom of the Sekaten tradition, and a learner analysis to gather data regarding students' characteristics, prior knowledge, and skill levels. Furthermore, a concept analysis is conducted to systematically outline the principles of quantities and measurement, which is then integrated with a curriculum analysis to ensure that the learning objectives align precisely with the stipulated learning outcomes.

Design

The design phase focuses on developing the initial draft of the physics e-worked example integrated with Sekaten local wisdom, alongside the construction of mathematical representation instruments. The e-worked example is developed in Google Sites. It comprises several core components: content pages, learning outcomes (CP) and objectives (TP), e-worked example solvers, practice exercises, evaluation pages, and discussion forums. Each page is specifically engineered to support the development of students' mathematical representation skills. Simultaneously, the test instrument is developed based on a synthesis of mathematical representation aspects, with each item representing a specific indicator. These test results serve as the primary data to evaluate the media's effectiveness in enhancing students' representational abilities.

Development

The development phase aims to obtain theoretical validation through expert judgment regarding content, construction, and media feasibility. Feedback and suggestions from experts serve as a primary guide for revisions before empirical testing. Validation results are transformed into interval data using the Method of Successive Interval (MSI) and analyzed quantitatively to determine feasibility categories. For the mathematical representation test instrument, expert validation is analyzed using Aiken's V, followed by empirical trials to ensure validity and reliability using Item Response Theory (IRT). This analysis was performed in detail to ensure instrument quality through item reliability and person reliability parameters for consistency, item fit (Infit/Outfit MNSQ) [24] to guarantee construct validity, and item difficulty levels on a logit scale to ensure the questions accurately differentiate students' ability profiles. The item fit parameters according to [25] are presented in Table 1.

Table 1. Parameters of item fit

Statistic Indeks	Range	Fit Item
INFIT MNSQ	0.77 – 1.33	Fit
OUTFIT MNSQ	0.50 – 1.50	Fit
PT Measure Corr	0.40 – 0.85	Fit

Implementation

The implementation phase is conducted to assess the effectiveness of the integrated e-worked example in improving students' mathematical representation profiles. This stage employs a quasi-experimental design, specifically the non-equivalent pretest-posttest group design. The field trial was conducted with 108 students across three randomly selected tenth-grade classes at SMA Negeri 1 Piyungan, Bantul. The experimental class used physics e-worked examples integrated with local wisdom from the Sekaten tradition, delivered through the 5E learning cycle model consisting of the engagement, exploration, explanation, elaboration, and evaluation stages. Contrast class 1 employed physics e-worked examples integrated with the Sekaten tradition local wisdom via the 3E learning cycle model, which includes the exploration, explanation, and elaboration stages. Contrast class 2 utilized standard school textbooks delivered through a conventional instructional model.

The mathematical representation profiles were mapped using a T-score analysis following the treatment in each respective class. Before the T-score analysis, student ability is represented by person-measure values (in logits). These person measure values are subsequently converted into T-scores (on a 100-point scale) using Equation 1.

$$T = 10(\text{measure}) + 50 \tag{1}$$

T = T – Score. The T-scores obtained can be categorized by reviewing the T-score distribution curve. The classification criteria for mathematical representation ability are calculated based on the standard deviation formula. The measurement criteria for both the mathematical representation profiles and attitudes toward local culture are presented in Table 2.

Table 2. Parameters of item fit

Range	Category
Score ≥ Mean + SD	High
Mean – SD ≤ Score < Mean + SD	Medium
Score < Mean – SD	Low

Evaluation

Finally, the evaluation phase involves the comprehensive analysis and interpretation of test results to illustrate the students' mathematical representation profiles and growth trends throughout the implementation. The significance of the improvement in students' ability profiles was analyzed using N-gain scores and t-tests to address the research questions on the effectiveness of integrating local wisdom in enhancing mathematical representation skills in physics.

III. Results and discussion

The feasibility of the mathematical representation test instrument was evaluated based on three aspects: content, construct, and language. According to Aiken's V criteria, an item is considered valid if the V-value exceeds 0.60 [26]. The validity testing used a 3-point rating scale with 8 expert raters. The results of this feasibility analysis yielded content-validity coefficients ranging from 0.88 to 0.94, indicating that the developed items are highly relevant and fall into the "highly feasible" category.

Empirical trials were subsequently conducted to determine the validity, reliability, and difficulty levels of the mathematical representation instrument. These trials used Item Response Theory (IRT) analysis to obtain accurate estimates of item validity. IRT analysis was also employed to assess instrument reliability, ensuring consistent measurement of students' underlying abilities [27]. The results showed that the Infit Mean Square (MNSQ) and Outfit Mean Square values aligned with IRT standards, with Infit MNSQ values falling within the 0.77–1.33 range and Outfit MNSQ values ranging from 0.5 to 1.5. These figures demonstrate a precise fit between the item data, respondents, and the model [28].

Furthermore, the Point-Measure Correlation (Pt Measure Corr) values were categorized as fit, falling within the $0.4 < Pt < 0.85$ range. Consequently, it can be concluded that the mathematical representation test items, as a whole, meet the required measurement standards. The reliability of the mathematical representation test items is presented in Table 3.

Table 3 Determination of test item reliability

Output	Value	Criteria	Description
Person Reliability	0.72	$0.70 \leq R < 0.80$	Acceptable
Item Reliability	0.95	$R \geq 0.90$	Excellent

The obtained person reliability value was 0.72, falling within the acceptable range. This figure indicates that the test demonstrates good consistency in distinguishing the proficiency levels among the individual students who completed the assessment [28]. Meanwhile, the item reliability was 0.95, meeting the excellent criterion. This exceptionally high value indicates that the items within the instrument are highly consistent, stable, and well-calibrated in measuring the intended construct of mathematical representation ability.

The field testing of the e-worked example media, integrated with the local wisdom of the Sekaten tradition, was conducted by implementing mathematical representation problems involving 108 students. These participants were divided into an experimental class, contrast class 1, and contrast class 2, with 36 students in each group. This media was implemented using a non-equivalent pretest-posttest control group design. To determine the effective contribution of each group to students' mathematical representation skills, an effect size analysis is required. The results of the effect size analysis are presented in Table 4.

Table 4. Effect size analysis results

Class	Hottelling's Trace			
	Sig	Partial Eta Squared	Effect Size	Category
Eksperiment	< 0.001	0.889	2.830	Very Large
Contras 1	< 0.001	0.823	2.156	Very Large
Contras 2	< 0.001	0.771	1.834	Very Large

Based on Table 4, the effect size analysis for the mathematical representation variable shows a significant effect across all three classes ($p < 0.001$). The experimental class recorded the highest effectiveness, with a partial eta squared of 0.889 and an effect size of 2.830. Meanwhile, contrast class 1 and contrast class 2 also demonstrated strong influence, with effect sizes of 2.156 and 1.834, respectively. Overall, all three groups fall into the "very large" category, indicating that the treatments provided had a substantial impact on students' mathematical representation abilities. The improvement in students' mathematical representation skills in each class is further illustrated by the estimated marginal means output in the profile plots section. These plots demonstrate a sharp increase from pretest to post-test, as shown in Figure 1.

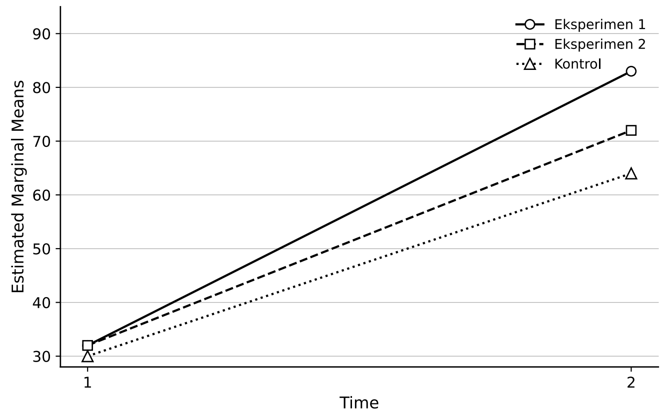

Figure 1. Enhancement of mathematical representation ability

Based on the profile plots in Figure 1, it is evident that the experimental class achieved the greatest improvement in mathematical representation ability compared to the contrast classes 1 and 2. Consequently, the implementation of e-worked example media integrated with Sekaten local wisdom yielded a superior effect in enhancing mathematical representation skills. Furthermore, the profile plots show no intersection between the lines, indicating that there was no significant interaction between the treatments across the different groups.

The analysis of the students' mathematical representation ability profiles was based on 12 items administered during the pretest and post-test phases. These problems were designed to measure three primary sub-aspects of mathematical representation ability: determining mathematical equations, analyzing mathematical equations, and interpreting the results of mathematical operations. The summary of the students' mathematical representation ability profiles is presented in Figure 2.

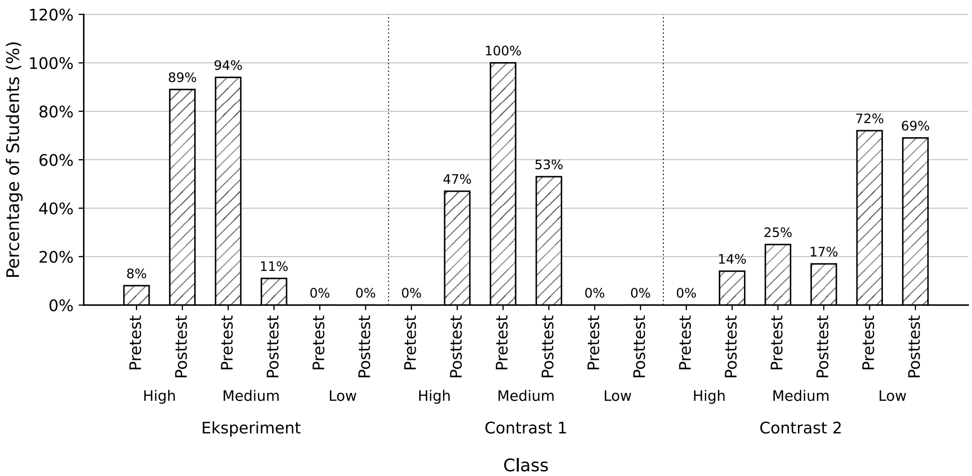

Figure 2. Mathematical representation ability achievement

The comparative analysis reveals that the experimental class, using e-worked example media integrated with Sekaten tradition local wisdom and the 5E learning cycle, achieved a superior increase in mathematical representation ability compared to the contrast groups. This is evidenced by the dramatic rise in students reaching the high-category proficiency from 8% to 89% in the experimental class, significantly outperforming the contrast class 2, which still had a high proportion of students in the low-category (69%) during the post-test. These results clearly indicate that the implemented instructional strategy is highly effective in enhancing students' capacity to determine mathematical equations and interpret mathematical operations, as further evidenced by the data on improvements in mathematical representation ability presented in Table 5.

Contrast class 1 also showed a significant increase of 59%, although it remained below the attainment of the experimental class. Conversely, contrast class 2 recorded a smaller gain of 49%, suggesting that conventional instructional methods are less effective in optimizing students' mathematical representation ability. Overall, these disparities reinforce that the use of e-worked example media integrated with local wisdom significantly enhances students' mathematical representation outcomes compared to traditional approaches.

Table 5. Estimated improvement in mathematical representation ability

Sub Aspect	Class		
	Eksperiment	Contras 1	Contras 2
Determine Mathematical Equations	75%	73%	55%
Analyzing Mathematical Equations	71%	52%	55%
Interpreting the Results of Mathematical Operations	79%	53%	37%
Average	75%	59%	49%

Determine Mathematical Equations

Pretest and post-test analyses indicate that students in the experimental and both contrast groups experienced a significant and consistent improvement in the sub-aspect of determining mathematical equations. This enhancement specifically reflects their proficiency in identifying relevant mathematical equations within presented physics contexts, as further documented in Figure 3.

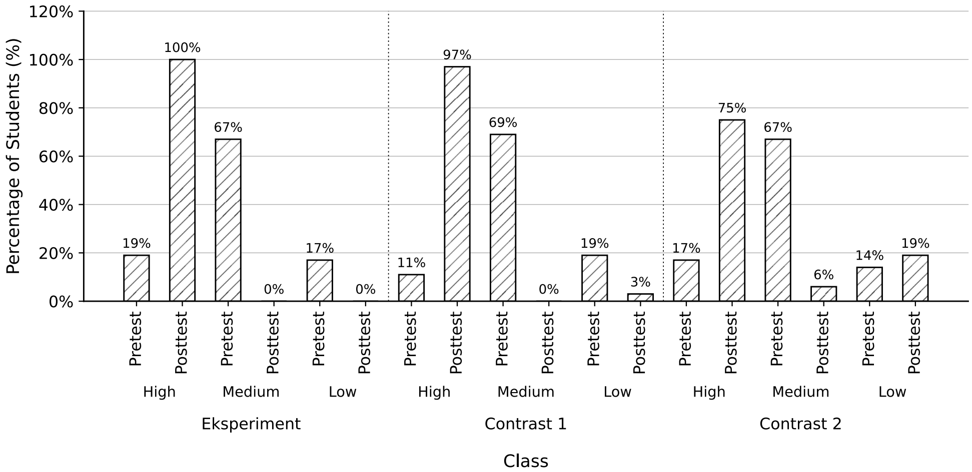

Figure 3. Performance in determining mathematical equations

Figure 3 illustrates a substantial increase in the percentage of students achieving the "high" category in the determining mathematical equations sub-aspect following the intervention. Most notably, the experimental class saw a dramatic rise from 19% to 100%, while the contrast class 1 also showed significant improvement, reaching 97%. In contrast, students in class 2 only reached 75% in the high category, with a considerable portion remaining in the medium (67%) and low (19%) categories. These results align with previous research indicating that the use of worked examples is more effective than conventional problem-solving in fostering the initial stages of schema acquisition, particularly in identifying appropriate mathematical models [29]. Furthermore, integrating Sekaten cultural elements as a contextual bridge mirrors findings that ethno-physics-based media significantly improve students' ability to translate physical phenomena into formal mathematical language [30]. This suggests that when students recognize the physical context, such as the mechanics embedded in traditional ceremonies, they can select appropriate equations more intuitively than with abstract, decontextualized textbook examples [31]. These findings, consistent with the estimated gains, suggest that conventional instructional methods are less effective than the implemented experimental approach at optimizing students' ability to formulate mathematical equations.

Analyzing Mathematical Equations

Pretest-to-posttest analyses indicate that students across all three groups, experimental, contrast 1, and contrast 2, demonstrated marked progress in analyzing mathematical equations, as illustrated in Figure 4. This improvement specifically reflects the students' ability to accurately analyze equations within the context of the provided physics problems. Notably, the experimental class exhibited superior performance in this sub-aspect compared to both contrast groups, suggesting a more effective development of analytical proficiency.

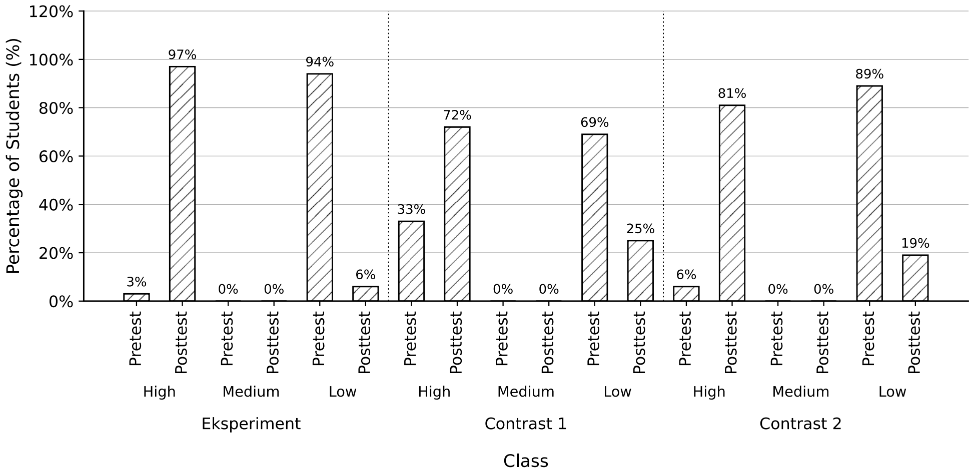

Figure 4. Performance in analyzing mathematical equations

Performance in mathematical equation analysis shows a significant surge in the experimental class, with the proportion of students in the 'high' category rising from 19% to 100% post-intervention. While contrast class 1 also showed substantial improvement (97%), contrast class 2 only reached 75%, with a significant portion remaining in the medium and low categories. These findings align with cognitive load theory, which suggests that structured digital scaffolds, such as e-worked examples, significantly outperform conventional modeling by reducing extraneous cognitive load during complex problem-solving [32]. Compared with prior studies that focused solely on general simulations [33], integrating the Sekaten tradition in this research provides a familiar cognitive anchor for students. This is consistent with recent evidence indicating that culturally responsive learning themes can enhance student engagement and conceptual retention in education [34]. Furthermore, the superiority of the 5E model over the 3E and conventional frameworks supports earlier findings that the 'Engagement' and 'Evaluation' stages are critical for refining mathematical precision and fostering student self-regulation [35]. Unlike the more theory-oriented 3E and conventional models, the 5E framework enables students to grasp concepts comprehensively through direct experience and practical application.

Interpreting the Results of Mathematical Operations

Evaluation of the pretest and post-test scores indicates an improvement in students' competence, particularly in the sub-aspect of interpreting the results of mathematical operations. This progress reflects the students' ability to meaningfully interpret the results of mathematical operations within the context of physics problems [36], [37]. The success indicator is evident in students' enhanced proficiency in correlating the concepts of quantity and measurement with relevant mathematical formulations. As illustrated in Figure 5, a consistent upward trend in the ability to interpret mathematical operation results was observed across all three groups: the experimental class, contrast class 1, and contrast class 2.

Performance in interpreting mathematical operation results, by sub-aspect, reveals significant disparities in improvement across the three groups. The experimental class demonstrated a dramatic surge in the "high" category, rising from 3% to 81%, while successfully eliminating the "low" category. In contrast, contrast class 1 achieved a moderate increase to 42%. In contrast, contrast class 2 showed very limited progress, with only 8% of students reaching the high category and 69% remaining in the low category post-intervention. These findings suggest that conventional methods are less effective, highlighting that integrating e-worked example media into the learning cycle model fosters active engagement and significantly enhances students' interpretative proficiency.

The profile of students' mathematical representation skills serves as a crucial indicator for evaluating the effectiveness of learning media, particularly in physics education. This study demonstrates that the implementation of e-worked example media, integrated with the learning cycle model, significantly enhances these skills. This competency encompasses three primary dimensions: the construction, analysis, and interpretation of mathematical equation results [38]. Research findings reveal that the experimental class, which implemented the interactive 5E learning cycle, recorded the greatest improvement at 75%. This is consistent with the post-test results, which show that 89% of students reached the "high" category, indicating their success in bridging physical concepts with mathematical equations.

In contrast, the first control group showed a lower improvement of 59%, with only 47% of students categorized as high achievers. This disparity is attributed to a simpler learning model, which limited students' opportunities for exploration and reflection [38]. Meanwhile, the second control group, utilizing conventional methods, recorded the lowest improvement at 49%, reinforcing the premise that traditional approaches are less effective in developing mathematical representation skills.

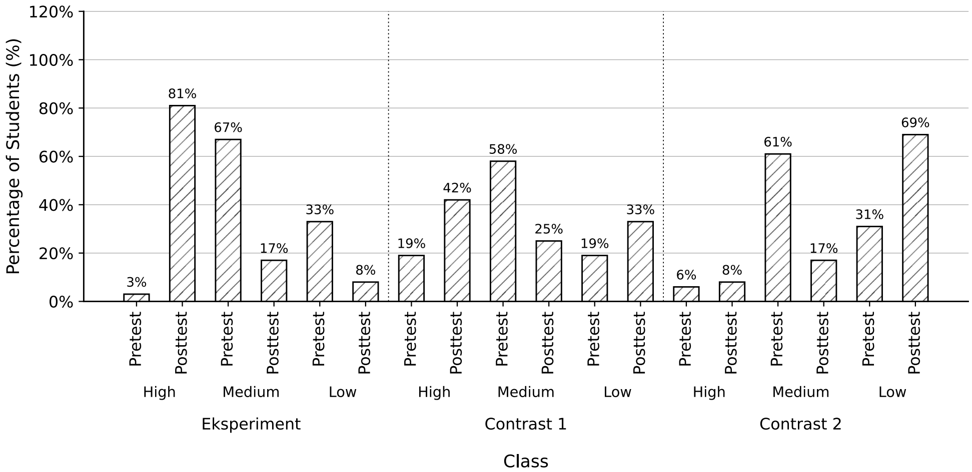

Figure 5. Performance in interpreting the results of mathematical operations

Data analysis further highlights variations within these mathematical representation skills, with the sub-aspect of interpreting mathematical operations emerging as the highest achievement, while analyzing mathematical equations remained the lowest. Although constructing equations is the fundamental basis for translating physical phenomena into mathematical models [39]–[41], proficiency in formula derivation does not inherently guarantee technical calculative fluency. This suggests a persistent gap between theoretical conceptual mastery and practical application in problem-solving. This deficiency in analytical skills is believed to stem from conventional instructional methods that are heavily dominated by theoretical lectures and insufficient practice [41]. As a response to this challenge, an e-worked example media integrated with the local wisdom of the Sekaten tradition is proposed as an innovative solution. The primary advantage of this media lies in providing structured solutions and interactive exercises relevant to physics content, which functions to strengthen the bridge between concepts and mathematical applications [42]. Through these simulations, students can directly visualize how mathematical equations operate within a physical context, thereby making the relationship between theory and practice more tangible.

IV. Conclusions

This study demonstrates that e-worked example media integrated with Sekaten local wisdom and the 5E learning cycle significantly improve students' mathematical representation profiles. The intervention successfully bridges the gap between abstract physics concepts and symbolic modeling, as evidenced by the experimental group's superior performance in determining, analyzing, and interpreting mathematical equations compared to conventional methods. These findings underscore the importance of combining structured cognitive guidance with culturally familiar contexts to foster 21st-century analytical skills in physics education. Despite these positive outcomes, this study has limitations, primarily its focus on a specific cultural context (Sekaten) and a limited sample size within a single geographic region, which may affect the generalizability of the results to diverse educational settings. Furthermore, the long-term retention of these representational skills was not assessed. Future research should explore the integration of other forms of local wisdom and evaluate the longitudinal impact of culturally responsive digital tools across various physics topics and broader student demographics.

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