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Meta-Analysis of the Effectiveness of Implementing Interactive Ethnomathematics-Based Learning Media

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ABSTRACT

This study aims to analyze the effectiveness of ethnomathematics-based interactive learning media on students' mathematical cognitive abilities using a meta-analysis approach. The data were obtained from 32 studies that met the inclusion criteria. Effect sizes were calculated using the standardized mean difference with a random-effects model to account for variability across studies. The results of the meta-analysis indicate that ethnomathematics-based interactive learning media have a strong positive effect on students' mathematical cognitive abilities, with an overall effect size of g = 1,48, which is classified as large. These findings suggest that integrating cultural contexts into interactive learning media is effective in enhancing students' understanding and cognitive performance in mathematics learning.

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1. INTRODUCTION

Ethnomathematics is a field of study that examines the relationship between culture and mathematical practices within society [1]. Ethnomathematics was introduced by Ubiratan D'Ambrosio in 1977 as part of an effort to decolonize mathematics education and to highlight the diversity of mathematical ways of thinking across cultures [2]. Ethnomathematics is not merely the study of mathematics within a particular culture; rather, it represents an interdisciplinary research program that connects mathematics, culture, history, and education [3]. Its objective is to demonstrate that mathematics is not solely abstract in nature, but is also rooted in traditions and everyday practices familiar to learners [4]. In educational contexts, ethnomathematics helps students understand mathematical concepts more concretely through cultural applications [5].

In Indonesia, research trends in ethnomathematics have shown a significant increase over the past few years [6].

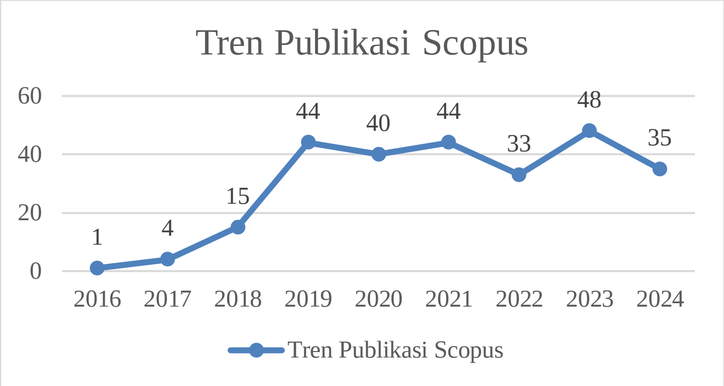

Figure 1. Trends in Scopus-Indexed Publications on Ethnomathematics Research (Riadi, 2024)

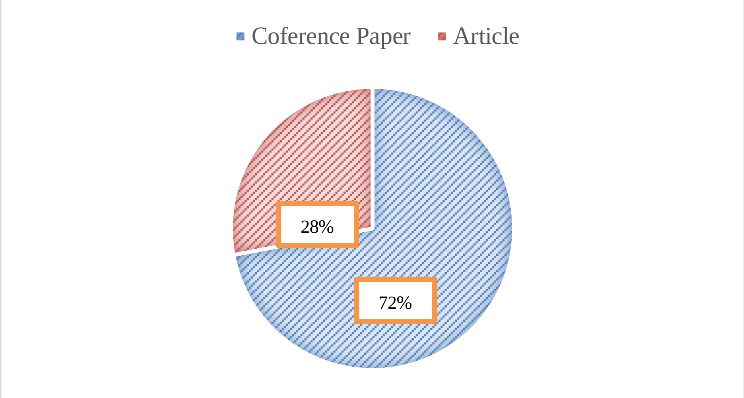

Figure 2. Percentage of Publication Types

As illustrated in the figures above, the number of publications related to ethnomathematics has increased significantly from 2016 to 2024, particularly since 2018. This increase coincides with the first Ethnomathematics Conference held in Yogyakarta on October 27, 2018, which also marked the establishment of the Ethnomath Association [7]. During this period, a total of 264 ethnomathematics-related studies were published, of which 191 were international conference proceedings indexed by Scopus. The dominance of conference proceedings publications is nearly three times greater than that of journal articles [8]. This indicates that ethnomathematics research has become increasingly popular among Indonesian academics.

However, even though the trend of ethnomathematics research in Indonesia continues to increase and many studies report its positive impact on students' mathematical abilities, the reality on the ground shows that this increase has not been reflected in the results of international assessments such as PISA [9].

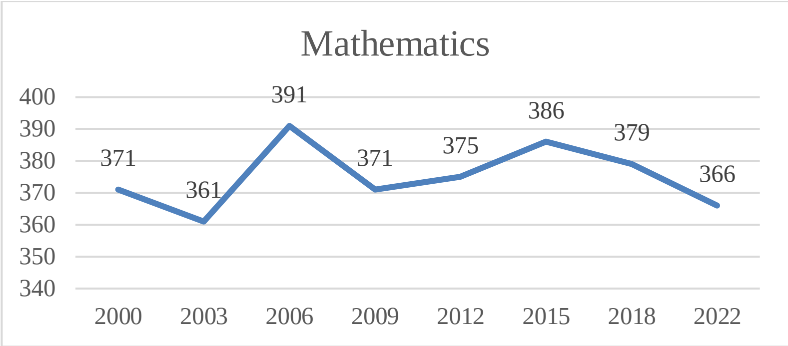

Figure 3. PISA 2022 Results (OECD, 2023)

Indonesia's mathematics performance in the Programme for International Student Assessment (PISA) from 2000 to 2022 indicates that Indonesia's ranking remains relatively low compared to other countries, far below the OECD average score of 500 [10]. This condition suggests stagnation in the quality of mathematics education in Indonesia. This finding is contradictory, considering that ethnomathematics is closely related to the contextualization of learning [11]. If students are able to contextualize mathematical concepts within their everyday lives, they should be better prepared to solve higher-order thinking skills (HOTS) problems related to real-world situations [12]. Problems designed using an ethnomathematical approach essentially aim to bridge theory and practice; therefore, students who are accustomed to this approach should also be capable of solving context-based real-life problems [13].

Interestingly, many studies show that ethnomathematics materials tend to focus predominantly on geometry. This dominance indicates that mathematical topics beyond geometry have not been extensively explored through an ethnomathematical approach [14]. Nevertheless, several studies have attempted to apply this approach to other concepts, such as limits, algebra, integer operations, and trigonometry. These efforts demonstrate that ethnomathematics has the potential to encompass a broader range of mathematical topics. Some examples of its implementation are presented in the following table.

Table 1. Description of Mathematical Abilities, Materials, and Cultural Aspects in Ethnomathematics-Based Approaches

Researcher (Year)	Mathematical Ability	Topic	Cultural Aspect
Yanti, Widada, and Zamzaili (2018)[15]	Mathematical Communication Skills	Limits of Algebraic Functions	*Kain Bersorek*
Widada, et al (2019)[16]	Problem-Solving Skills	Mathematical Literacy	Local Culture
Herawaty, et al (2019)[17]	Conceptual Understanding Skills	Trigonometry	Traditional Houses of Rejang Lebong
Perdana and Isrokatun (2019)[18]	Mathematical Conceptual Understanding	Integer Operations	*Kerupuk Melarat*
Putri and Zaenuri (2022)[19]	Mathematical Connection Skills	Cartesian Coordinates	Woven Fabric

In addition to the dominance of geometry-related content, the table also shows that tangible cultural objects largely represent cultural aspects used in ethnomathematics-based mathematics learning as instructional media. This dominance is likely due to the ease of linking concrete objects to mathematical concepts, making them easier to understand and integrate into the learning process. However, intangible cultural elements such as customary practices, calendrical systems, traditional games, and others also embody rich mathematical values and hold great potential to be adapted for instructional purposes [20].

Nevertheless, one of the main challenges in implementing ethnomathematics-based approaches in learning lies in the limited availability of interactive and contextual learning media. For instance, irrelevant content quality or content that is misaligned with the curriculum can confuse and reduce students' motivation [21]. Poorly structured instructional content further hampers students' understanding of complex mathematical concepts [22]. This situation necessitates the development of learning media that are not only visually engaging but also pedagogically robust and aligned with curriculum standards.

These issues are inseparable from the evolution of the Indonesian curriculum, which has undergone numerous changes since independence, including revisions in 1947, 1952, 1964, 1968, 1975, 1984, 1994, 2004, 2006, 2013, and most recently in 2022 [23]. Frequent and rapid curriculum changes have created uncertainty for teachers and schools in adjusting instructional tools, resulting in the integration of specific local cultural elements within ethnomathematics often being overlooked or deprioritized [24]. However, under the latest curriculum, the *Merdeka Curriculum*, the integration of ethnomathematics into learning should be more effectively implemented. The *Merdeka Curriculum*, which emphasizes project-based learning and differentiated instruction with a focus on literacy and numeracy, provides opportunities for ethnomathematics linking mathematical concepts with local culture to be integrated into learning outcomes across various grade levels when supported by appropriate learning media [25].

2. METHOD

This study employs a meta-analysis conducted since January 2025, with the primary data sources consisting of scholarly articles obtained from the Google Scholar database covering the period 2020–2024. A quantitative descriptive approach was applied to synthesize the findings of primary studies related to interactive ethnomathematics-based mathematics learning media. The research population comprised all relevant articles identified through specific keywords, while the sample was selected using purposive sampling based on predetermined criteria, including the availability of effect size data, educational level, research theme, and publication language. Data were collected through documentation techniques from articles that met the inclusion criteria, then classified and analyzed to calculate effect sizes. The research instrument consisted of a coding sheet used to systematically identify study characteristics and empirical findings, thereby supporting a valid, reliable, and comprehensive data synthesis.

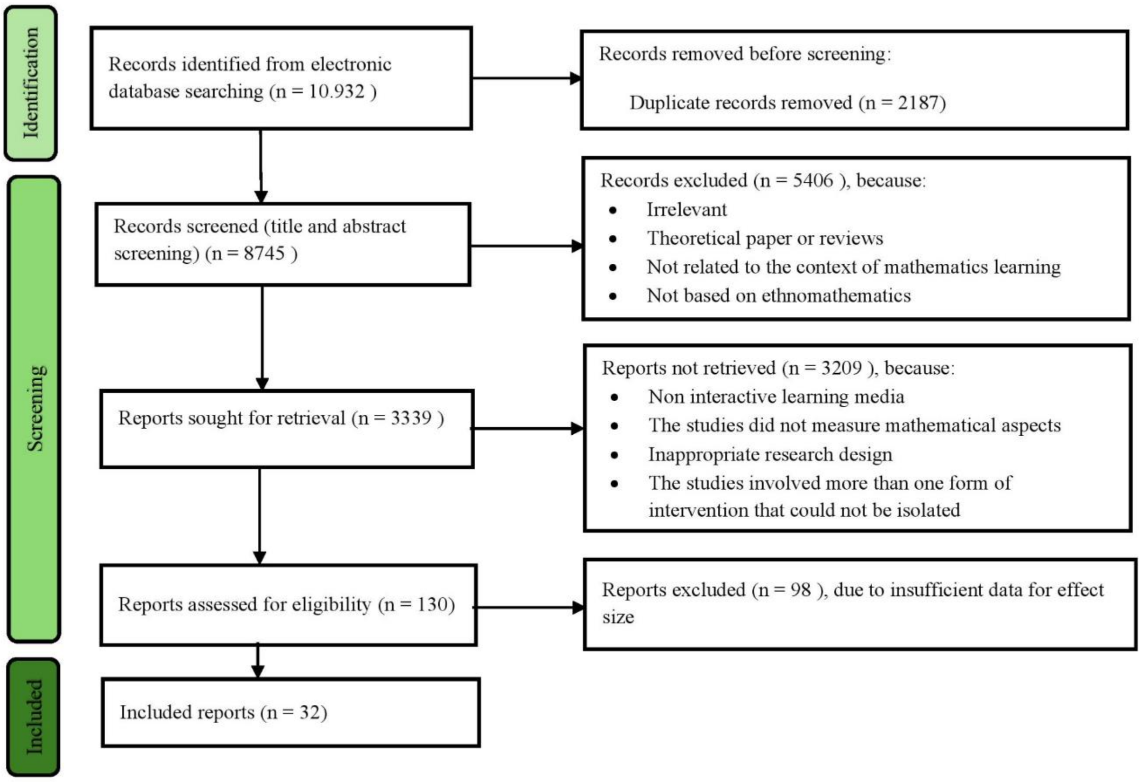

Figure 4. Diagram PRISMA Flowchart

Effect Size Calculation and Statistical Models

In this study, the Hedges'g parameter, also known as the standardized mean difference (SDM), was used to determine the effect size. The Hedges'g calculation was developed by Hedges in 1985 as a standard measure for measuring the impact of a treatment [26]. This calculation will assess the overall effectiveness of developing interactive mathematics learning media based on ethnomathematics, based on the sample of articles taken. Furthermore, it will examine the effectiveness of ethnomathematics based on cultural artifacts, the learning media used, and the material taught.

In performing the Hedges'g calculation, the initial step is to assume that study *K* (the study results) presents two treatment groups: a control group (index 1) and an experimental group (index 2). For each study from study 1 to study K, it is assumed that there are n_1 in the control group and n_2 in the experimental group. Where n_1 and n_2 are the sample sizes of the two groups.

The outcomes measured in the study are $\overline{X_1}$ for i from 1 to n_1 for the control group and $\overline{X_2}$ for *i* from 1 to n_2 for the experimental group. Then, assume the control group values. $\overline{X_1}$ are sampled from a normal distribution with mean μ_1 and standard deviation (SD) σ_1 and the experimental group values $\overline{X_2}$ with mean μ_2 and standard deviation (SD) σ_2.

The standard sampling estimators for μ_1 and μ_2 are their respective sample means are as follows:

$$\overline{X_1} = \frac{\sum_{i=1}^{n_1} X_{1i}}{n_1}$$

$$\overline{X_2} = \frac{\sum_{i=1}^{n_2} X_{2i}}{n_2}$$

And the standard sampling estimators for σ_1 and σ_1 are their respective standard deviations are as follows:

$$\overline{SD_1} = \sqrt{\frac{\sum_{i=1}^{n_1} (X_{1i} - \overline{X_1})^2}{n_1 - 1}}$$

$$\overline{SD_2} = \sqrt{\frac{\sum_{i=1}^{n_2} (X_{2i} - \overline{X_2})^2}{n_2 - 1}}$$

If it is assumed that the standard deviation of the control and intervention groups is the same in the study $\sigma_1 - \sigma_2 = \sigma$, then:

$$\overline{SD_2} = \sqrt{\frac{(n_1 - 1)SD_1^2 + (n_2)SD_2^2}{n_1 + n_2 - 2}}$$

This estimate allows for an estimate of the difference between the means of the experimental and control studies in each study, expressed in standard deviation (SD) units. Hedges proposed the γ index as a population parameter used to describe the size in statistical power analysis, known as **g.** The symbol used for the effect size parameter is γ, while for the in-sample estimate, it uses the symbol **g.**

$$\gamma = \frac{\mu_1 - \mu_2}{\sigma}$$

The estimates used for the Hadges'g study sample are as follows:

$$g = \frac{\overline{X_1} - \overline{X_2}}{SD}$$

For funnel plots or heterogeneity tests, it is necessary to apply the standard error formula. Assuming that the experimental and control groups have equal variances, then each group will have a standard error calculated as follows:

$$SE_{(g)} = \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

Referring to the standard theory of variance equality in linear regression, this standard error is used to determine the confidence interval and *p-value* for γ, using the t-distribution and degrees of freedom of $n_1 + n_2 - 2$. In meta-analysis, the main goal is to estimate the weighted mean of γ, which will be equal to the general value if all γs are identical. In general, this meta-population parameter is defined as the weighted sum of γ using the weight ω, where the weight is a combination of the sample sizes of the experimental and control groups $n = n_1 + n_2$.

$$\bar{\gamma} = \frac{\sum_{i=1}^{K} \omega\gamma}{\sum_{i=1}^{K} \omega}$$

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The estimator for the meta-population γ is obtained by summing with weights ω, which can be estimated using the consistent estimator W.

$$\bar{g} = \frac{\sum_{i=1}^{K} \omega\gamma}{\sum_{i=1}^{K} \omega}$$

In the case where ω is a collection of n, then W is also n.

Outlier Detection

In meta-analyses, random effects models are commonly used to explain variation that cannot be explained solely by within-study variability. However, this method is sometimes inadequate when faced with outlier studies. Therefore, identifying outliers is a crucial step, given that outliers have very extreme effect sizes and deviate significantly from the overall effect [27]. In this study, R software version 2023.9.0.463 was used to detect outliers, utilizing the 'metafor' and 'dmetar' features. The 'dmetar' feature includes the 'find.outliers' function, which implements an algorithm to remove outliers [28]. Additionally, the 'gosh.diagnostic' function was used, which utilizes various clustering algorithms to identify data patterns. Of the several available algorithms, the k-means algorithm was specifically selected for this analysis [29].

Moderator Variable Analysis

Analysis of moderator variables is crucial in meta-analysis because it can help researchers understand the factors that influence effect size variation across studies, as well as provide information for evaluating the effectiveness of existing interventions and formulating more impactful interventions in the future [30]. In this study, the moderator variables analyzed included culture type, materials, educational level, thinking skills, and media used. The heterogeneity of research findings across studies was explored using a heterogeneity test (Q test). A key finding from the Q statistic indicates the likelihood that each study draws from the same population. In particular, the significant variation in the collective impact of each element on the moderator variable, indicated by a significant Q value, underscores the importance of moderator variable analysis [31]. Analysis of all moderator variables in this study was conducted using a model approach, such as ANOVA. This model displays the mean effect size (g) in each group, its 95% confidence interval (CI), and heterogeneity between groups (Qb). A significant Qb value indicates a meaningful difference in the aggregate effect size among the components of the moderator variable. All analyses were performed using R software version 2023.9.0.463 with the help of the 'meta' feature [32].

Publication Bias Assessment

Publication bias assessment aims to identify potential bias in the analyzed literature and its impact on the overall conclusions of the meta-analysis. To assess publication bias in this meta-analysis, a three-stage approach was used. The first step was performed using a funnel plot and Egger's regression test. Visual inspection of the funnel plot was used as an initial step to detect possible asymmetry. A symmetrical distribution in a funnel plot is considered an indication of the absence of publication bias [33]. This graphical representation also facilitates the identification of potential outliers and provides an overview of the potential for publication bias. Next, Egger's regression test, known as a quantitative approach to assessing asymmetry in a funnel plot, was performed. This test measures the extent of asymmetry in the funnel plot, thus providing a quantitative dimension in evaluating potential publication bias. This evaluation aims to determine whether there is a systematic relationship between the effect size and the precision of a study, which could indicate publication bias.

In addition to these two methods, the Trim and Fill method was also used to strengthen the publication bias analysis. This method is a common technique for correcting asymmetry in funnel plots. Through this method, suspected missing studies were identified from the funnel plot, and then adjustments were made to the meta-analysis results to include these studies in an estimated manner, resulting in a more accurate effect size estimate. This comprehensive approach allows researchers to more robustly address potential publication bias and enhance the credibility of the meta-analysis findings. To conduct the publication bias analysis, R software version 2023.9.0.463 was used, with the assistance of the statistical packages 'meta' and 'metafor'. The integration of these various statistical tools allows for a comprehensive exploration of publication bias, thus supporting the robustness of the analysis and increasing the reliability of the meta-analysis findings in explaining the influence of game-based learning media on students' mathematical analytical thinking skills.

3. RESULTS AND DISCUSSION

The article search process for this study involved two stages: identification and screening. In the identification stage, articles were searched using Google Scholar using predetermined keywords and limited to publication years between 2020 and 2024. The research procedure was structured based on meta-analysis stages and was guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines as a reference in the study selection process.

Result

Main Analysis Results Before Detecting Outliers

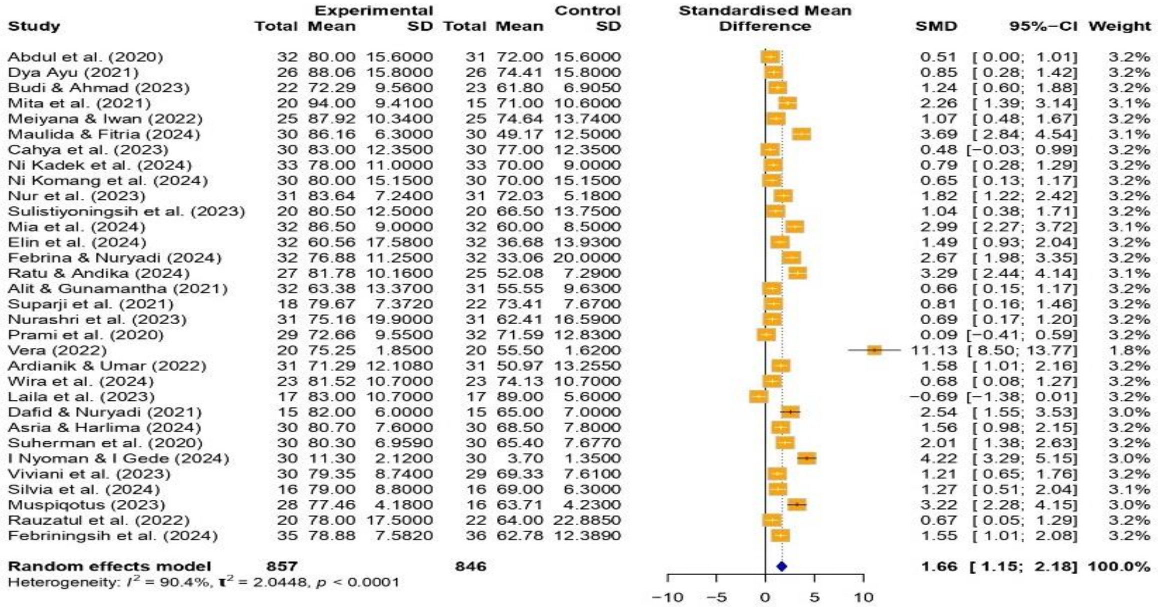


Figure 5. Forest Plot for 32 Studies (Pre–Outlier Detection)

The meta-analysis using a random-effects model indicates that the mean effect size (SMD) across the 32 analyzed studies is 1.664 ($p < 0.0001$), demonstrating that the integration of ethnomathematics in mathematics learning has a statistically significant effect on improving student achievement. The 95% confidence interval ranges from [1.1516; 2.1771] (Figure 5), suggesting that the findings can be generalized with a high level of confidence. According to the effect size classification proposed by Thalheimer and Cook (2002), this effect size falls into the high category (*excellent effect size*), as it exceeds the threshold of ≥ 1.45. This indicates that the implementation of ethnomathematics exerts a strong influence on enhancing students' mathematical abilities compared to non–culture-based instructional approaches.

Furthermore, the analysis reveals a very high degree of variability in effect sizes across studies ($Q = 324.24$; $df = 31$; $p < 0.0001$), with an I^2 value of 90.4%, indicating very high heterogeneity. This finding suggests substantial variation in the effect sizes reported among the included studies.

Outlier Detection

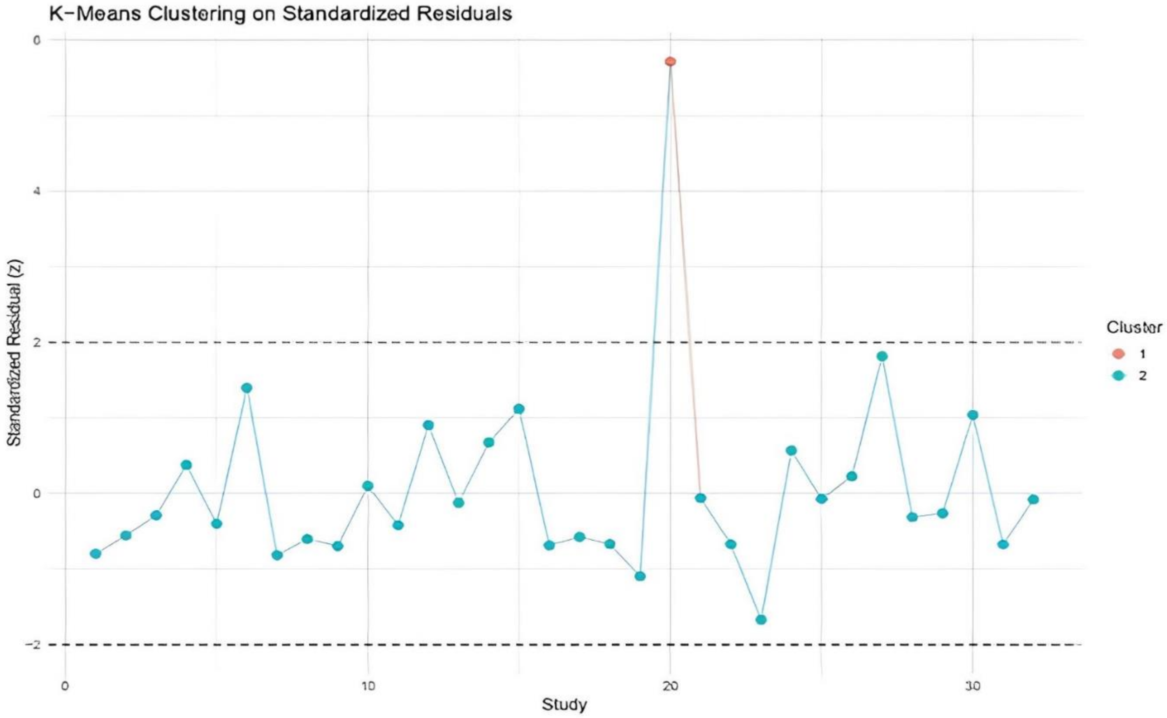


Figure 6. K-Means Plot for Detecting Outliers

In identifying outliers data points that deviate substantially from the norm it is important to note that such observations can have a significant impact on the overall results. Therefore, it is recommended to remove outliers and subsequently reassess their cumulative impact. The K-Means analysis plot (Figure 6) shows a study with a data point located far from the horizontal line (Study 20), which is identified as an outlier. The analysis results indicate that one study was identified as an outlier, namely the study conducted by Vera (2022).

Summary Effect Analysis After Removing Outliers

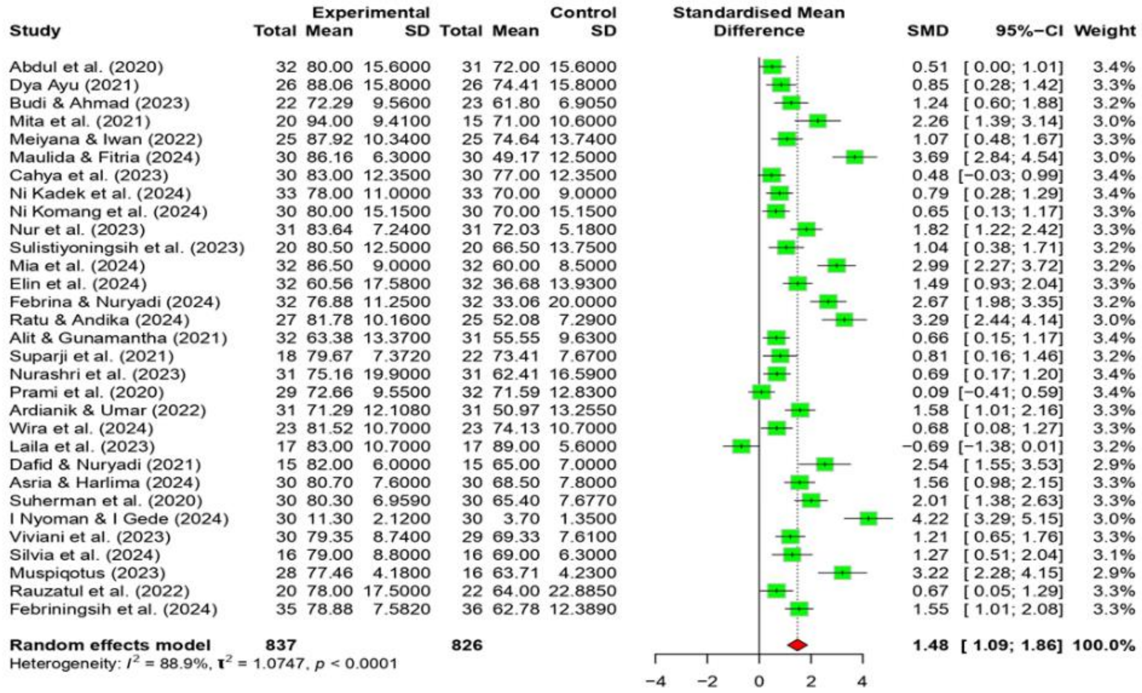


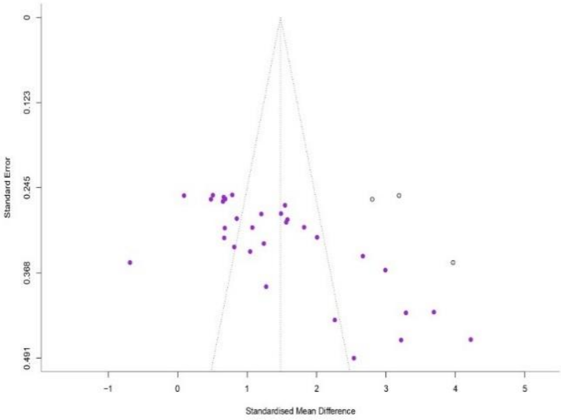
Figure 7. Forest Plot for 31 Studies (Post–Outlier Detection)

After removing the single study identified as an outlier, a reassessment of the collective impact of the remaining 31 studies was conducted. In these studies, the effect sizes (ES) ranged from –0.69 to 4.22 (Figure 7). Among them, one study (3.23%) reported a negative effect size, indicating that ethnomathematics-based interactive learning media were not more effective than conventional instruction in the control group. In contrast, 30 studies (96.77%) reported positive effect sizes, suggesting that students in the experimental groups using ethnomathematics-based interactive learning media achieved higher levels of higher-order thinking skills (HOTS) compared to students in the control groups.

Overall, the meta-analysis results demonstrate a positive and statistically significant combined effect size, with $g = 1.4777$ ($p < 0.0001$; 95% CI = [1.0939; 1.8615]), which is slightly lower than the original effect size prior to the removal of the outlier study. This finding underscores the importance of the outlier detection process in meta-analysis. Nevertheless, similar to the pre–outlier removal condition, the overall effect size remains within the *excellent* category. Figure 4.3 presents a forest plot illustrating the effect sizes and confidence intervals of each study.

In addition, the heterogeneity test results remain significant ($Q = 270.19$; $df = 30$; $p < 0.0001$) with an I^2 value of 88.9%, indicating substantial variation among the included studies. According to Higgins et al., I^2 values above 75% reflect high heterogeneity, meaning that most of the observed variance represents true differences in effect sizes rather than sampling error. This high level of heterogeneity highlights the need to explore potential moderator variables that may explain variations in the effectiveness of ethnomathematics-based interactive learning media.

Publication Bias Evaluation



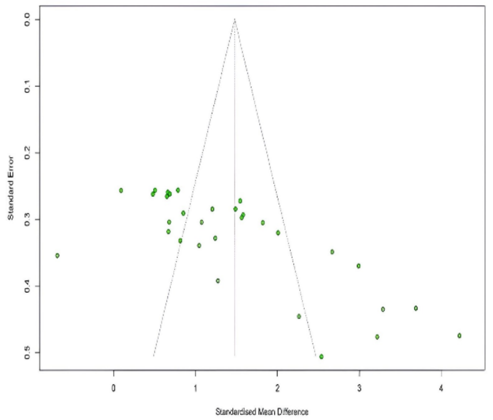


Figure 8. Funnel Plot Using the Trim and Fill Method **Figure 9**. Funnel Plot Using Egger's Method

The funnel plot in Figure 4 illustrates the results of publication bias analysis using the Trim and Fill method. The distribution of data points appears asymmetrical, particularly on the left side of the plot, indicating the possible absence of small studies with negative or non-significant results. This asymmetrical pattern suggests a tendency for studies reporting positive effects to be published more frequently than those reporting low or null effects. The Trim and Fill method subsequently estimates the presence of "missing" studies to restore symmetry to the plot. This adjustment indicates that some of the positive effects observed in the initial results may be inflated due to publication bias; therefore, the meta-analysis findings should be interpreted with caution. This result is consistent with the literature, which notes that educational research is often affected by the *file-drawer problem*, whereby studies with non-significant findings remain unpublished.

In contrast to the Trim and Fill method, the funnel plot in Figure 5 presents the results of Egger's regression test for detecting publication bias based on the relationship between effect size and standard error. Visually, the plot appears more symmetrical, particularly in the central region of the funnel, indicating that publication bias may be less pronounced than suggested by the Trim and Fill results. The absence of a strongly skewed pattern or a clear small-study effect supports the interpretation that heterogeneity or natural variation among studies may be the primary source of dispersion, rather than publication bias alone. Differences between the results of Egger's test and the Trim and Fill method are common in meta-analyses and underscore the importance of employing more than one method to assess publication bias. Therefore, the interpretation of the meta-analysis findings should consider both approaches in a complementary manner to obtain a more accurate assessment of the overall validity of the results.

Discussion

Despite the growing trend of integrating ethnomathematics into the learning process, which has resulted in numerous empirical studies testing the effectiveness of ethnomathematics-based interactive learning media, individual studies have yielded varying findings regarding their impact on students' mathematical cognitive abilities. Furthermore, a comprehensive synthesis of these study results is still lacking. This study aims to fill this gap through a meta-analysis approach. The results indicate that, overall, the implementation of ethnomathematics-based interactive learning media positively impacts students' mathematical cognitive abilities.

The scope of this meta-analysis focuses on the effectiveness of ethnomathematics-based interactive learning media. Due to the limited data available, direct comparisons of this study's results with other similar studies are challenging. However, comparisons between this study's results and previous relevant meta-analyses are possible. The findings of this study align with those of several previous meta-analyses examining the effectiveness of ethnomathematics in mathematics learning in general.

After removing outliers, the meta-analysis results in this study showed that the overall effect size was large, at g = 1.48 (95% CI [1.00; 1.62]), which is considered excellent based on the Effect Size classification of Thalheimer & Cook (2002). This value indicates that the implementation of ethnomathematics-based interactive learning media provides strong and consistent improvements in students' mathematical cognitive abilities. This high effect size indicates that the combination of the ethnomathematics approach and interactive learning media creates a highly conducive learning environment for students' cognitive development. Interactive media allows students to actively interact with mathematical representations, while the local cultural context integrated through ethnomathematics serves as a cognitive anchor, helping students connect abstract concepts with real-world experiences [34]. This process supports the formation of deeper conceptual understanding while facilitating higher-level cognitive activities such as analysis, reasoning, and problem-solving.

These findings reinforce a previous meta-analysis by Ratu et al., who reported the positive effects of ethnomathematics-based digital learning, which had a large effect (d = 0.87) on students' mathematical cognitive abilities [35]. This large effect indicates that the integration of local cultural contexts, when packaged interactively, can enrich students' knowledge construction processes and expand their higher-order thinking capacity. Furthermore, the integration of local cultural contexts in interactive media also has the potential to increase the relevance and meaning of learning, thereby encouraging higher cognitive engagement. When students learn mathematics through cultural representations close to their lives, extrinsic cognitive load can be minimized, while students' cognitive resources can be allocated optimally to understanding concepts and solving problems. This ultimately contributes to the improvement of overall mathematical cognitive abilities.

4. CONCLUSION

Based on the results of this study, the following conclusions were obtained interactive learning media based on ethnomathematics were overall proven to be effective, as indicated by the meta-analysis results showing an effect size of g = 1.48 (large/excellent category) in enhancing students' mathematical cognitive abilities.

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