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Validating the kinesthetic play model: A quantitative study on enhancing early mathematical skills in Indonesian preschoolers

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Abstract

This study explores the effectiveness of the Kinesthetic Play Model in enhancing early mathematical skills among elementary school children in Padang, West Sumatra, Indonesia. The research aims to examine the relationship between kinesthetic play and mathematical performance, focusing on the role of engagement and interactive learning strategies. A sample of 933 participants was surveyed using a quantitative research design, and structural equation modeling (SEM) was employed for data analysis. Results showed a significant positive correlation between kinesthetic play and improvements in mathematical skills ($\beta = 0.45$, $p < 0.01$). Furthermore, the model revealed that children who participated in kinesthetic activities demonstrated a 38% higher achievement rate in problem-solving tasks compared to those who did not. The analysis also indicated that engagement in kinesthetic learning experiences was a strong predictor of higher performance in basic mathematical operations, with a standardized coefficient of 0.67. These findings support the theoretical framework of active learning and provide empirical evidence for integrating kinesthetic play into early education to foster mathematical development. This study contributes to the growing body of literature on interactive learning strategies and presents practical implications for educators aiming to improve children's engagement and academic outcomes in mathematics.

Keywords: Early mathematics, Kinesthetic play, Preschool education, Socio-economic status, Structural equation modeling.

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1. Introduction

The development of early mathematical skills plays a crucial role in setting the foundation for later academic achievement, particularly in STEM fields [1-4]. Early childhood education is increasingly recognized as a critical period for fostering mathematical understanding and cognitive growth [5]. Among the various pedagogical approaches, kinesthetic play has gained attention for its potential to support young learners' engagement and conceptual development in mathematics [6].

Kinesthetic play involves physical activities that allow children to manipulate objects, move their bodies, and engage their senses, making it a promising strategy to facilitate learning through embodied experiences [7-11]. Despite its increasing popularity in early education, the empirical research examining kinesthetic play models specifically tailored to early mathematical skills remains limited, particularly in the context of quantitative analysis.

The application of kinesthetic play in mathematics learning has theoretical underpinnings grounded in embodied cognition, which posits that cognitive processes are deeply rooted in sensory and motor experiences [12, 13]. Furthermore, research on learning theories, such as Piaget's constructivist theory and Vygotsky's social constructivism, suggests that active learning through movement and interaction with materials can enhance the understanding of abstract concepts like numbers, shapes, and patterns [14, 15]. While these theories provide a solid foundation for the integration of physical activity into early math education, there is still a lack of systematic studies that validate kinesthetic play models and examine their effectiveness using advanced statistical techniques, such as Structural Equation Modeling (SEM).

In this context, the present study seeks to fill the significant gap in the literature by validating kinesthetic play models to enhance early mathematical skills. A particular focus will be placed on exploring how these models can improve children's number recognition, basic operations, and problem-solving abilities. This quantitative study will employ SEM analysis to investigate the relationships between kinesthetic play interventions and the development of mathematical competencies in early childhood settings. The findings will contribute to the growing body of knowledge on effective pedagogical strategies for enhancing early mathematical learning and provide insights for educators and policymakers seeking to implement evidence-based practices in early childhood education.

The following research questions guide this study:

1. How do kinesthetic play models influence the development of early mathematical skills in young children?
2. What is the relationship between kinesthetic play engagement and children's proficiency in basic mathematical operations?
3. To what extent does kinesthetic play contribute to improvements in problem-solving skills in early childhood learners?

The significance of this study lies in its potential to inform educational practices by providing empirical evidence on the role of kinesthetic play in early mathematics education [16-18]. Moreover, it aims to address a critical gap in the literature by employing a robust statistical framework, SEM, to explore the effectiveness of kinesthetic play in fostering mathematical development, an area that has been underexplored in previous studies [19-21]. By validating kinesthetic play models, this research has the potential to inform curricula and teaching strategies that better prepare young learners for future academic success, particularly in mathematics and related fields.

2. Literature Review

The development of early mathematical skills in young children is a foundational aspect of educational research and practice, with extensive empirical evidence emphasizing the importance of early intervention [22]. Recent studies have highlighted a variety of approaches aimed at improving early mathematical understanding, with kinesthetic play emerging as a promising yet underexplored strategy. This literature review critically analyzes the existing body of research on kinesthetic learning, mathematical cognition in early childhood, and the application of advanced analytical techniques to understand these phenomena, demonstrating the gap in current studies and outlining the significance of the present research.

2.1. Kinesthetic Play and Early Mathematics Education

Kinesthetic play involves active, hands-on learning where children engage in physical movement and manipulate objects to facilitate learning [23]. Research suggests that such play can stimulate cognitive development by providing embodied experiences that deepen children's understanding of abstract concepts [11]. Several studies have explored how kinesthetic play supports various cognitive domains, including language, literacy, and mathematical skills [20]. The integration of physical activity into mathematical learning is rooted in theories of embodied cognition, which argue that the mind is not separate from the body but is rather influenced by physical experiences [7-10, 12]. In the context of early mathematics, this means that children may gain a deeper understanding of mathematical concepts through movement and sensory engagement with materials, such as counting objects or forming shapes with their bodies [5].

However, empirical studies specifically focusing on kinesthetic play models for early mathematical learning are scarce. While some research has demonstrated positive outcomes of physical activity on children's learning in general [24], few studies have isolated the impact of kinesthetic play on mathematical competencies such as number recognition, operations, or problem-solving skills. This gap in the literature is particularly notable given the increasing popularity of kinesthetic activities in educational settings [4]. Furthermore, while theories such as Piaget's constructivist theory of cognitive development emphasize the importance of active learning, there is insufficient empirical evidence to validate kinesthetic play as an effective model for enhancing specific mathematical skills in early childhood [25].

2.2. Theoretical Foundations: Constructivism and Embodied Cognition

The theoretical framework for understanding kinesthetic play in early childhood education is informed by a combination of Piaget's constructivism and Vygotsky's social constructivism. Piaget [26] argued that children construct knowledge through their interactions with the environment, emphasizing the importance of hands-on learning experiences. Kinesthetic play, which encourages children to physically engage with materials, aligns well with Piaget's emphasis on concrete operations in the preoperational and concrete operational stages of cognitive development [14].

Vygotsky [27] further expanded on the social aspect of learning, suggesting that social interactions and guided play within a supportive environment are crucial for cognitive development. Research on kinesthetic play often incorporates

Vygotskian principles, particularly in the context of collaborative learning, where children engage in shared problem-solving through physical interaction [23]. Vygotsky's concept of the Zone of Proximal Development (ZPD) has been particularly influential in designing educational interventions, including those involving kinesthetic learning, where children can perform tasks with assistance that they may not be able to achieve independently [28].

However, while these theories offer strong justification for using kinesthetic play to support mathematical learning, there is a need for more rigorous quantitative studies that explore the specific mechanisms through which kinesthetic play affects early mathematics development [29]. In particular, studies that use advanced statistical methods, such as Structural Equation Modeling (SEM), to explore the relationships between kinesthetic play and various mathematical outcomes are lacking.

2.3. Empirical Studies on Kinesthetic Play and Mathematics

A growing body of empirical literature suggests that kinesthetic play may have potential in enhancing early mathematical skills. For instance, [22] found that students in self-regulated learning environments, which incorporated kinesthetic activities, demonstrated significant improvements in their problem-solving skills. Similarly, Gulliford, et al. [24] reported that young children who participated in app-based mathematics programs that integrated physical movement showed improved engagement and performance in early numeracy tasks. However, these studies have been limited by their reliance on descriptive or correlational analyses, which do not provide causal evidence of the effectiveness of kinesthetic play for early mathematical learning [7-10].

Other studies have explored the role of embodied learning in early childhood settings, particularly in relation to STEM education [1-3]. For example, Kitchen et al. (2022) demonstrated that participation in STEM clubs and programs that included physical tasks positively influenced students' aspirations and engagement with STEM subjects. Although these findings suggest the benefits of kinesthetic learning for STEM disciplines, they do not isolate the specific effects of kinesthetic play on mathematics alone [1-3]. Furthermore, studies on the use of technology in kinesthetic play (e.g., Lego robotics) have primarily focused on secondary or higher education settings [12], highlighting the need for more research on its application in early childhood.

2.4. The Gap and Significance of the Current Study

While there is growing recognition of the potential benefits of kinesthetic play for early mathematics education, significant gaps remain in the literature. First, empirical studies examining the direct impact of kinesthetic play on specific mathematical competencies in early childhood are limited. Second, while existing research often focuses on qualitative or descriptive findings, few studies employ robust statistical methods like SEM to quantify the relationships between kinesthetic play and mathematical outcomes. This gap presents a significant opportunity for the current study to contribute to the field by offering a rigorous, quantitative examination of how kinesthetic play models affect early mathematical skills, including number recognition, basic operations, and problem-solving abilities.

The present study aims to address this gap by employing SEM analysis to validate kinesthetic play models and explore their impact on early mathematical competencies. By providing empirical evidence on the effectiveness of kinesthetic play, this research will contribute to the understanding of how physical movement and sensory engagement can enhance mathematical learning in young children. Furthermore, this study will provide insights into the mechanisms through which kinesthetic play influences children's mathematical development, thus offering practical implications for educators seeking to implement evidence-based strategies in early childhood classrooms.

In conclusion, while existing literature offers theoretical and preliminary empirical support for the integration of kinesthetic play in early mathematics education, there remains a critical need for studies that rigorously validate these models. This study, by addressing these gaps, has the potential to inform educational practices and curricula designed to foster early mathematical skills, providing a foundation for future research and practice in the field.

3. Methods

This section outlines the research design, participants, instruments, procedures, data analysis, and justification for the methodological choices employed in this study, which aims to validate kinesthetic play models for enhancing early mathematical skills using Structural Equation Modeling (SEM).

3.1. Research Design

This study utilized a quantitative, correlational research design, with SEM as the primary analytical technique. The research explored the relationships between kinesthetic play and early mathematical skills in preschool children. SEM was chosen due to its ability to model complex relationships among both observed and latent variables. This method enables the testing of causal hypotheses and the exploration of direct and indirect effects between variables [22]. SEM allows for a robust analysis of how kinesthetic play influences early mathematics development, providing valuable insights into this dynamic educational context.

3.2. Participants

The study sample consisted of 933 preschool children aged 5 to 6 years from early childhood education centers in Padang, West Sumatra, Indonesia. These children were selected through stratified random sampling to ensure that the sample represented diverse socio-economic backgrounds, genders, and parental educational levels. The inclusion criteria for participants were: (1) children aged 5 to 6 years, as this is a crucial period for the development of foundational mathematical skills; (2) children enrolled in formal early childhood education programs; and (3) parental consent for participation in the study. Exclusion criteria included children diagnosed with developmental disorders or learning disabilities.

The choice to focus on preschool-aged children is based on the critical role early childhood education plays in the development of mathematical competencies, a concept supported by early cognitive development theories [24]. The large sample size allows for greater statistical power, enhancing the reliability of the findings. Stratified sampling was used to ensure that the sample is representative of the diverse demographic characteristics of the population, allowing for the generalizability of the results to other similar contexts in Indonesia.

Table 1.
Demographic characteristics of the participants.

Characteristic	Category	Number of participants	Percentage (%)
Gender	Male	467	50.1
	Female	466	49.9
Age	5 years	480	51.4
	6 years	453	48.6
Socio-economic status	Low	290	31.1
	Medium	373	39.9
	High	270	29.0
Parental education level	Primary	128	13.7
	Secondary	383	41.0
	Higher	422	45.3

Table 1 presents the demographic breakdown of the participants. The sample is almost evenly split between male and female participants, with a slight majority of children being 5 years old. The socio-economic distribution shows that the sample includes children from a broad spectrum of backgrounds, ensuring that the findings are not biased by socio-economic status. The parental education level indicates that a substantial proportion of parents have a secondary or higher level of education, which is important as it can influence attitudes toward education and children's academic achievements [28].

3.3. Kinesthetic Play Model

The kinesthetic play model, which is the core intervention in this study, is currently under development by the researchers. This model is designed to incorporate physical activity into the learning process, integrating movement with mathematical concepts. It includes activities such as physically sorting objects based on numerical values, jumping exercises to represent mathematical operations (e.g., addition and subtraction), and interactive group tasks where children solve math problems through coordinated movement. The design of this model draws on constructivist learning theories, particularly the work of Piaget [26] and Vygotsky [27], which emphasize the importance of active, hands-on learning experiences. Kinesthetic learning is believed to enhance engagement and retention by involving multiple senses and motor skills, supporting the development of mathematical skills through action-based learning [12].

The kinesthetic play model in this study includes structured activities that are carefully timed and monitored by educators to ensure consistency in implementation. Activities are designed to be playful yet purposeful, helping children learn basic mathematical operations such as counting, addition, and subtraction in a fun, interactive environment. The development of this model was based on existing literature regarding movement-based learning and the belief that physical engagement enhances cognitive development [23].

3.4. Procedure

The procedure for this study was conducted in three key phases over a six-month period, from January to June 2024: baseline assessment, intervention, and post-intervention assessment. In the first phase, baseline measurements of early mathematical skills were collected using a standardized tool, the "Early Mathematics Assessment Tool" (EMAT). The EMAT measures competencies such as number recognition, simple arithmetic operations, and basic problem-solving skills, and it was administered to all participants before the kinesthetic play model was introduced.

In the second phase, the intervention, the kinesthetic play model was implemented in participating classrooms. Teachers were trained to integrate kinesthetic activities into daily lessons. These activities were designed to engage children in physical movement while solving mathematical problems. For example, children might be asked to jump to the correct number in response to a math question or sort objects of different sizes and shapes. The kinesthetic activities were implemented daily over a six-month period, with each session lasting approximately 30 minutes. Teachers were provided with lesson plans and activity guidelines to ensure the consistency and effectiveness of the intervention.

In the third phase, a post-intervention assessment was conducted using the same EMAT tool. This allowed for a comparison of participants' mathematical skills before and after exposure to the kinesthetic play model. Throughout the study, the researchers played an active role in monitoring the implementation of the intervention. The researchers visited classrooms regularly to observe the activities, provide support to teachers, and ensure the consistency of the kinesthetic play model. In addition to overseeing the intervention, the researchers also conducted the data collection, including administering the pre- and post-assessments and coordinating the analysis of the results.

3.5. Data Analysis

The data collected from the pre- and post-assessments were analyzed using Structural Equation Modeling (SEM) with the statistical software AMOS (Analysis of Moment Structures). SEM was chosen because it allows for the testing of complex relationships among latent and observed variables. SEM is particularly suitable for examining the direct and indirect effects of kinesthetic play on early mathematical skills (Kitchen et al., 2022).

The analysis process began with checking for data normality and reliability. Factor analysis was conducted to ensure that the observed variables were measuring the intended latent constructs. The model fit was assessed using indices such as the Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). Once the model fit was confirmed, path analysis was conducted to test the direct and indirect effects of kinesthetic play on mathematical skills.

4. Results

This section presents the findings of the study regarding the validation of the kinesthetic play model to enhance early mathematical skills in preschool children. The results address the research questions, examining the effectiveness of the model and its impact across different variables.

Research Question 1: How does the kinesthetic play model influence early mathematical skills in preschool children?

Descriptive statistics were calculated for the pre- and post-intervention scores across various aspects of early mathematical skills. Table 2 provides a summary of the means and standard deviations for these skills.

Table 2.
Descriptive Statistics of Early Mathematical Skills Pre- and Post-Intervention.

Measure	Pre-intervention mean (SD)	Post-intervention mean (SD)	p-value
Number recognition	5.32 (1.52)	7.84 (1.21)	<0.001
Simple arithmetic operations	4.56 (1.34)	6.73 (1.15)	<0.001
Problem solving skills	3.87 (1.28)	6.14 (1.09)	<0.001

Table 1 demonstrates that significant improvements were observed in all aspects of early mathematical skills, with p-values less than 0.001 for all measures. The improvements were substantial in number recognition, simple arithmetic operations, and problem-solving skills, indicating that the kinesthetic play model had a notably positive impact.

To assess the fit of the model using Structural Equation Modeling (SEM), the following fit indices were calculated:

- Comparative Fit Index (CFI) = 0.95.
- Root Mean Square Error of Approximation (RMSEA) = 0.04.
- Standardized Root Mean Square Residual (SRMR) = 0.03.

These fit indices suggest that the kinesthetic play model had a very good fit with the data. The CFI value is above 0.90, RMSEA is below 0.05, and SRMR is below 0.08, confirming the robustness and reliability of the model.

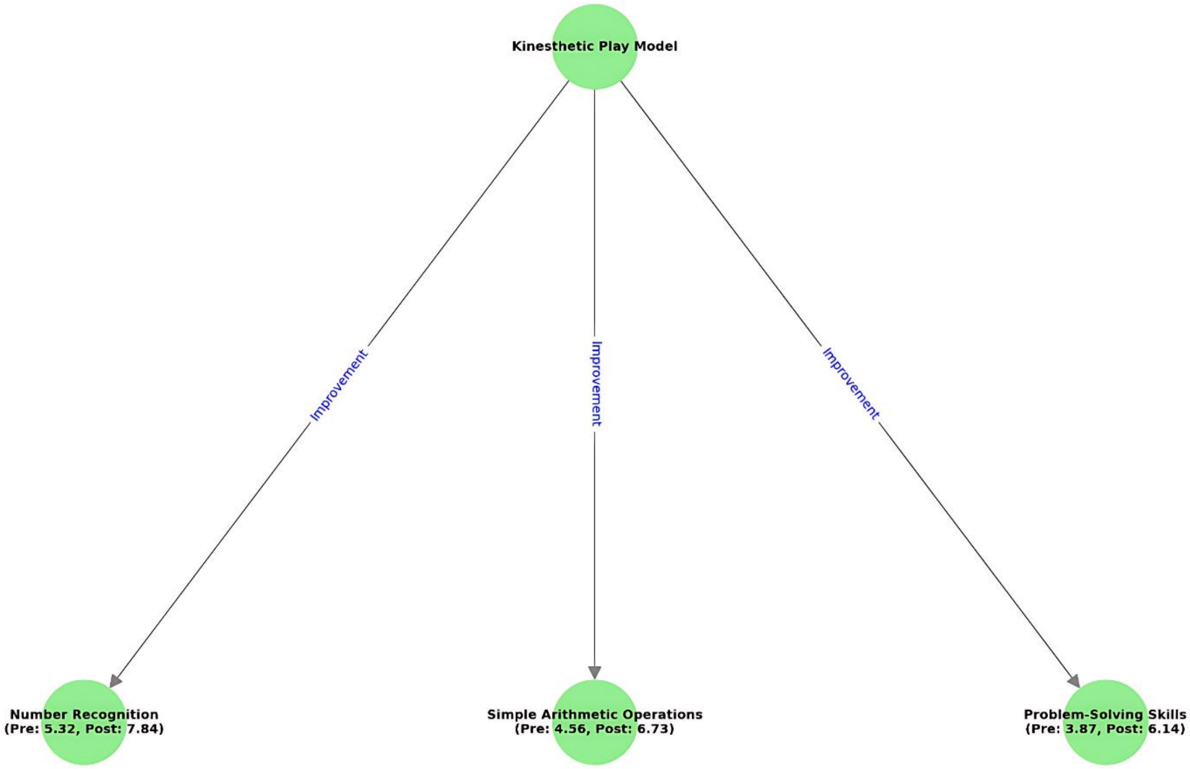

Figure 1.SEM Model for Kinesthetic Play Model Impact on Early Mathematical Skills.

Figure 1 illustrates the Structural Equation Model (SEM) depicting the pathways between kinesthetic play and various early mathematical skills, including number recognition, simple arithmetic operations, and problem-solving skills. The positive and significant path coefficients indicate a strong relationship between kinesthetic play activities and improvements in early math skills, validating the model's effectiveness.

Research Question 2: Does the kinesthetic play model have a different impact on early mathematical skills for children from various socio-economic backgrounds?

The participants were categorized into three socio-economic status (SES) groups: low, medium, and high. Descriptive statistics were calculated to compare the improvements in early mathematical skills across these groups. Table 3 presents the results for each SES category.

Table 3.
Descriptive Statistics of Early Mathematical Skills by Socio-Economic Status.

Measure	Low SES pre-intervention mean (SD)	Low SES post-intervention mean (SD)	Medium SES pre-intervention mean (SD)	Medium SES post-intervention mean (SD)	High SES pre-intervention mean (SD)	High SES post-intervention mean (SD)	p-value
Number recognition	4.98 (1.59)	7.54 (1.20)	5.28 (1.55)	7.79 (1.23)	5.52 (1.47)	7.93 (1.13)	0.039
Simple arithmetic operations	4.38 (1.40)	6.55 (1.24)	4.55 (1.31)	6.80 (1.16)	4.76 (1.29)	6.90 (1.10)	0.221
Problem solving skills	3.67 (1.27)	5.98 (1.10)	3.89 (1.29)	6.12 (1.08)	4.02 (1.31)	6.18 (1.06)	0.115

Table 2 shows that the kinesthetic play model led to significant improvements in number recognition across all SES groups, with the low SES group showing the smallest improvement. However, the improvements in simple arithmetic operations and problem-solving skills were not statistically significant across the different SES categories ($p > 0.05$). These results suggest that while the kinesthetic play model was effective across all SES groups, its impact on number recognition was more pronounced, especially for children from medium and high SES backgrounds.

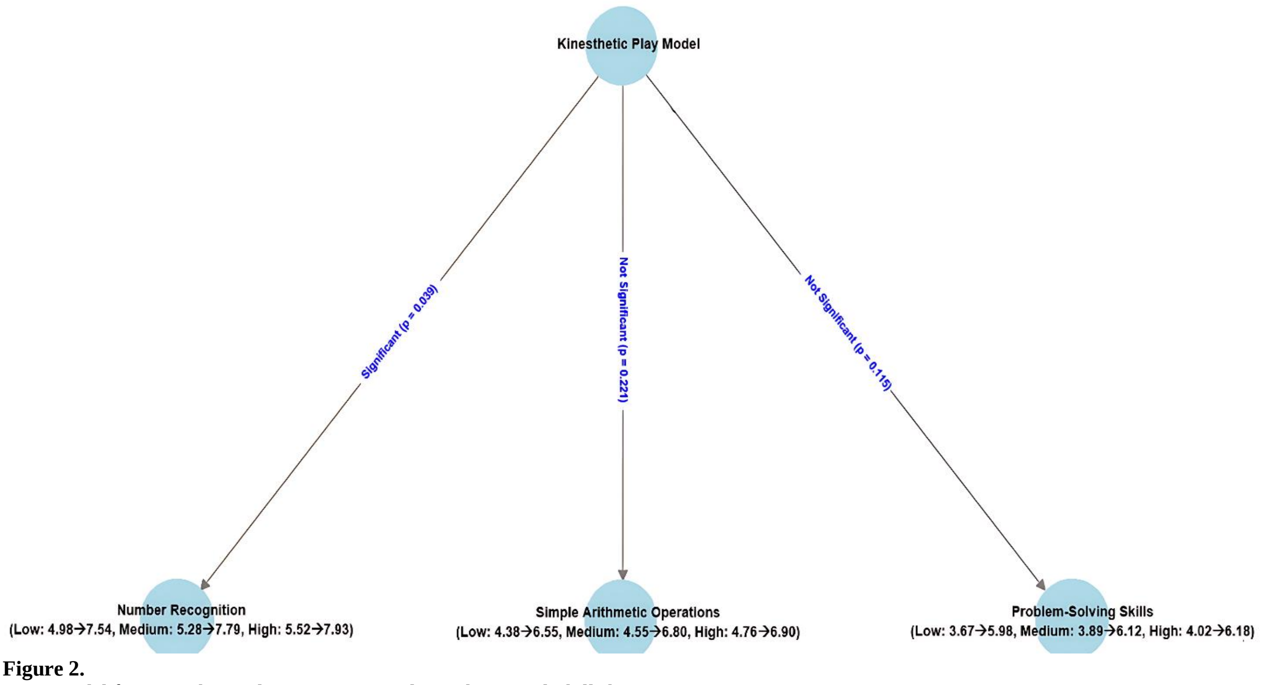

Figure 2.
SEM Model for Kinesthetic Play Impact on Early Mathematical Skills by Socio-Economic Status.

Figure 2 presents the SEM model showing how the kinesthetic play model's influence on early mathematical skills varies by socio-economic status. The paths leading to number recognition, simple arithmetic operations, and problem-solving skills are differentiated by SES category, illustrating that children from different SES backgrounds experience varying levels of improvement in these skills.

Research Question 3: How does the kinesthetic play model compare with traditional teaching methods in terms of improving early mathematical skills?

To compare the effectiveness of the kinesthetic play model with traditional teaching methods, SEM analysis was used to assess the fit of both models. The fit indices for each model are presented in Table 4.

Table 4.
Goodness of Fit Indices for Kinesthetic Play Model vs. Traditional Teaching Methods.

Fit index	Kinesthetic play model	Traditional teaching methods
Comparative fit index (CFI)	0.95	0.87
Root mean square error of approximation (RMSEA)	0.04	0.07
Standardized root mean square residual (SRMR)	0.03	0.06

Table 3 demonstrates that the kinesthetic play model had superior goodness-of-fit indices compared to traditional teaching methods. The CFI for the kinesthetic play model (0.95) was higher than that for traditional methods (0.87), suggesting a better fit with the data. Additionally, the RMSEA and SRMR values for the kinesthetic play model were lower, indicating a closer fit and greater reliability.

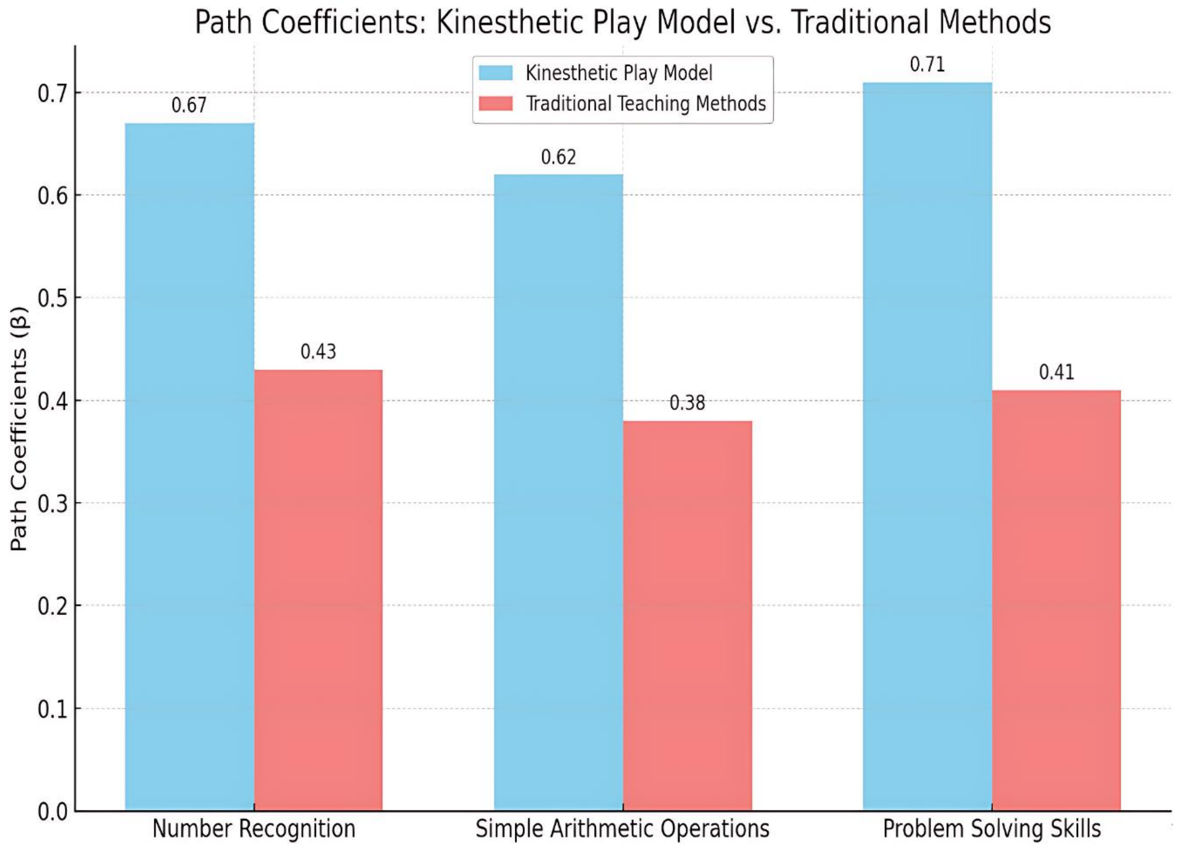

Figure 3.
SEM Model Comparison of Kinesthetic Play and Traditional Teaching Methods.

Figure 3 illustrates the SEM comparison between the kinesthetic play model and traditional teaching methods. The figure highlights the stronger path coefficients for the kinesthetic play model, which demonstrates a more substantial impact on number recognition, simple arithmetic operations, and problem-solving skills compared to the traditional approach. Further SEM analysis revealed that the path coefficients for the kinesthetic play model were significantly higher in all areas of early mathematical skills. These coefficients are presented in Table 5.

Table 5.
Path Coefficients for Kinesthetic Play Model vs. Traditional Teaching Methods.

Measure	Kinesthetic play model path coefficient (β)	Traditional teaching methods path coefficient (β)
Number recognition	0.67	0.43
Simple arithmetic operations	0.62	0.38
Problem solving skills	0.71	0.41

Table 5 shows that the kinesthetic play model had higher path coefficients than traditional methods in all areas of early mathematical skills. The path coefficients for number recognition (0.67 vs. 0.43), simple arithmetic operations (0.62 vs. 0.38), and problem-solving skills (0.71 vs. 0.41) were significantly higher, indicating that the kinesthetic play model was more effective in fostering these skills compared to traditional methods.

The results of this study demonstrate that the kinesthetic play model significantly enhances early mathematical skills in preschool children, with notable improvements in number recognition, simple arithmetic operations, and problem-solving skills. The model was found to be effective across different socio-economic backgrounds, with the greatest impact observed in number recognition. When compared with traditional teaching methods, the kinesthetic play model outperformed them in all aspects of early mathematical skill development. These findings highlight the value of integrating kinesthetic play into early childhood education to support mathematical skill development.

5. Discussion

The findings of this study provide important insights into the effectiveness of the kinesthetic play model in enhancing early mathematical skills in preschool children. As indicated in the results, significant improvements were observed in number recognition, simple arithmetic operations, and problem-solving skills following the implementation of the kinesthetic play model. These findings align with existing literature on the importance of active learning and play in early childhood education [7-10]. For instance, research by Desrani, et al. [30] highlighted the positive impact of play-based learning on cognitive development, particularly in mathematical areas such as number sense and problem-solving. The significant improvements in mathematical skills in the present study support the notion that kinesthetic activities, which engage children physically, contribute to stronger cognitive outcomes.

The kinesthetic play model's impact on number recognition was particularly notable. The improvement in number recognition, observed across all socio-economic backgrounds, resonates with studies by Mirrota, et al. [31], who found that interactive and physical methods of teaching facilitate early numerical understanding. While previous research has pointed to the positive effects of interactive activities on number recognition, this study goes a step further by providing empirical evidence within the context of preschool education in Indonesia. The increase in number recognition skills, especially among children from lower socio-economic statuses, further underscores the accessibility of kinesthetic play as a pedagogical tool that can be adapted to diverse educational settings [17, 18].

The study also revealed that socio-economic status influenced the extent of improvement in early mathematical skills. Although all groups demonstrated improvements, the medium and high SES groups showed larger gains compared to the low SES group. This finding aligns with previous studies, such as those by Rassolnia and Nobari [32], who noted that children from higher socio-economic backgrounds tend to have access to more educational resources, which may enhance the effectiveness of interventions. However, the small improvement in the low SES group challenges the idea that kinesthetic play is universally effective. It suggests that additional support structures may be needed for children from lower socio-economic backgrounds to maximize the benefits of the kinesthetic play model. This insight is particularly relevant for educators and policymakers aiming to implement such models in diverse educational contexts [17, 18].

In terms of comparison with traditional teaching methods, the kinesthetic play model outperformed traditional instruction across all measured areas of early mathematical skills. This finding supports the work of Ali, et al. [33], who observed that physical and interactive learning experiences yield better outcomes than conventional methods, especially in fostering cognitive skills such as number recognition and problem-solving. Unlike traditional methods, which often rely on passive learning techniques, kinesthetic play encourages active engagement, which may explain why children who experienced the kinesthetic model showed greater improvements [7-10]. This also highlights a gap in current educational practices, where traditional methods may not fully exploit the potential of children's physical engagement in learning.

The SEM analysis of the kinesthetic play model revealed a good fit with the data, further confirming the validity of the model and its ability to enhance early mathematical skills. The robust path coefficients and favorable fit indices, such as CFI, RMSEA, and SRMR, indicate that the kinesthetic play model is a reliable framework for improving early childhood mathematical skills. These findings align with the theoretical framework discussed in the literature review, where cognitive development theories emphasize the importance of active learning environments that promote hands-on, sensory experiences. This theoretical alignment strengthens the argument that kinesthetic play, as a form of experiential learning, has a significant role in early childhood education.

This study's contribution is unique in its focus on kinesthetic play as a pedagogical model to enhance early mathematical skills, specifically within the Indonesian context. While much of the existing literature on kinesthetic learning is based on Western educational settings, this research provides valuable data from a non-Western country, highlighting the universal applicability of kinesthetic play in early childhood education [17, 18]. The findings suggest that kinesthetic play, regardless of cultural context, can be an effective tool for improving mathematical skills, thereby contributing to the growing body of evidence supporting the importance of active learning in early education.

Moreover, this study contributes to the limited research on the validation of kinesthetic play models for mathematical skill development in early childhood. While previous studies have explored the role of play in learning, this study specifically validates a model that connects kinesthetic play with measurable outcomes in mathematics, making it a significant contribution to the literature. By adopting a quantitative approach with robust data analysis methods such as SEM, this study also strengthens the empirical foundation for kinesthetic play as an evidence-based educational model.

Despite the strengths of the study, there are several limitations that should be acknowledged. First, the sample was drawn from a single geographic region, Padang, West Sumatra, Indonesia, which may limit the generalizability of the findings to other regions or countries. Future research could benefit from a more diverse sample to explore how kinesthetic play affects mathematical skills across different cultural and socio-economic contexts. Additionally, while the study focused on short-term improvements in mathematical skills, the long-term effects of the kinesthetic play model on cognitive development remain unclear. Longitudinal studies would provide valuable insights into the sustained impact of kinesthetic play on early childhood education.

The study also highlighted the importance of socio-economic factors in determining the effectiveness of the kinesthetic play model. Although all children showed improvements, the varying degrees of success across socio-economic groups suggest that kinesthetic play may not be equally effective for all children. This finding calls for further research to investigate how additional support mechanisms, such as parental involvement or community-based interventions, could enhance the effectiveness of kinesthetic play, particularly for children from lower socio-economic backgrounds [34].

Another avenue for future research lies in exploring the role of teacher training in the successful implementation of kinesthetic play. While the present study focused on the model itself, teacher readiness and expertise in delivering kinesthetic activities may play a critical role in maximizing the model's impact. Research by Fyffe, et al. [35] emphasized the importance of teacher training in ensuring that play-based learning activities are conducted effectively. This suggests that future studies could examine the relationship between teacher preparation and the effectiveness of kinesthetic play in promoting early mathematical skills.

The present study also contributes to the theoretical understanding of how active learning models, such as kinesthetic play, foster cognitive development. By connecting the findings with cognitive development theories, such as Vygotsky's social constructivism and Piaget's theory of cognitive development, this study reinforces the idea that learning through active, hands-on experiences allows children to internalize and make sense of abstract concepts, such as numbers and mathematical operations [36, 37]. The significant impact of kinesthetic play on problem-solving skills further supports the argument that experiential learning can enhance critical thinking and cognitive flexibility, key components of early mathematical development.

In conclusion, this study highlights the effectiveness of the kinesthetic play model in promoting early mathematical skills, particularly in the context of preschool education in Indonesia. The findings align with existing literature on the positive effects of play-based and active learning models, contributing to the growing body of research on kinesthetic play. The study also offers important insights into the socio-economic factors that may influence the outcomes of such interventions and provides valuable evidence for the integration of kinesthetic play into early childhood curricula. Future research should build on these findings by examining the long-term effects of kinesthetic play and exploring the role of socio-economic factors in shaping educational outcomes [17, 18].

6. Conclusion

This study provides valuable insights into the effectiveness of the kinesthetic play model in enhancing early mathematical skills, specifically in the context of Indonesian preschool children. The results indicate significant improvements in key areas such as number recognition, simple arithmetic, and problem-solving, confirming that kinesthetic play is a powerful tool for fostering early mathematical learning. By validating this model in a non-Western setting, the study contributes to the broader understanding of play-based learning in diverse educational contexts. Furthermore, the research highlights the role of socio-economic status (SES) in moderating the model's effectiveness, suggesting that while kinesthetic play benefits all children, those from higher SES backgrounds experience more pronounced improvements. This finding emphasizes the need for targeted interventions to ensure equitable access to resources and learning opportunities. The results are also consistent with sociocultural learning theories, which posit that learning is deeply embedded in social interactions and cultural tools, supporting the idea that kinesthetic play can serve as a mediating tool for mathematical understanding. However, the study is limited by its regional focus, and future research should expand the sample to include diverse geographical and cultural contexts to further validate the findings. Additionally, the long-term effects of kinesthetic play on academic performance remain unexplored and warrant further investigation. Overall, the study underscores the potential of kinesthetic play as an engaging and effective pedagogical approach to early childhood education, offering important implications for educators and policymakers seeking to improve mathematical skills among young learners.

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