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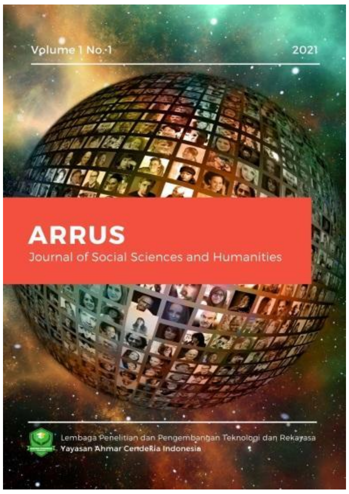

*Corresponding author: Sri Rika Amriani.H, Department of Early Childhood Teacher Education, Faculty of Education, Universitas Negeri Makassar, Makassar, Indonesia

E-mail: sri.rika.amriani@unm.ac.id

RESEARCH ARTICLE

Sound–Motion Mapping in STEAM-Based Music and Dance Learning to Develop Early Childhood Gross Motor Skills*

Sri Rika Amriani*, Herman , Nur Chafidah,& A.Sri Wahyuni Asti

Pendidikan Guru Pendidikan Anak Usia Dini, Fakultas Ilmu Pendidikan, Universitas Negeri Makassar, Makassar, Indonesia.

Abstract: This study examines the effect of STEAM-based music and dance learning using a sound–motion mapping approach on the gross motor skills of children aged 5–6 years. The study employed a quantitative approach with a quasi-experimental design using a non-equivalent control group design. The participants consisted of 24 children from TK Magfira Makassar, Indonesia, divided into an experimental group ($n = 12$) and a control group ($n = 12$). Data were collected through structured observation and gross motor performance tests covering locomotor skills, stability skills, and movement synchronization with rhythm and tempo. The research instrument was validated and demonstrated good reliability (Cronbach's Alpha = 0.79). Data were analyzed using descriptive statistics and the non-parametric Mann-Whitney U test. The results show that children who participated in STEAM-based music and dance learning with the sound–motion mapping approach achieved significantly higher gross motor scores than those who received conventional music and dance instruction. The experimental group obtained a mean post-test score of 22.33, whereas the control group achieved a mean score of 13.58. Statistical analysis revealed a significant difference between the two groups ($Z = -4.182$, $p < 0.001$). The findings suggest that integrating music and dance through sound–motion mapping effectively enhances movement coordination, balance, body control, and motor timing, supporting the development of gross motor skills in early childhood through structured, sensory-rich STEAM activities.

Keywords: Sound–Motion Mapping, STEAM-Based Learning, Music And Dance, Gross Motor Skills, Early Childhood

1. Introduction

Physical-motor development in early childhood is an essential component in building children's ability to explore their environment and preparing their learning readiness (Jayani & Mawaddah, 2025; Nurkamelia, 2019). The World Health Organization (WHO) emphasizes that physical activity plays a crucial role in muscle growth, bone health, and children's motor and cognitive development. However, WHO reports indicate that more than 80% of children and adolescents worldwide do not meet the recommended level of physical activity (World Health Organization, 2024). This condition reflects the increasing prevalence of low-movement activity patterns among children from an early age, which may potentially hinder the development of their fundamental motor skills. The phenomenon of low physical activity among children is a global issue that directly affects gross motor development from early

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childhood. In line with this report, international empirical studies show that limited children's engagement in physical activity may prevent gross motor development from progressing optimally, particularly in movement coordination, balance, and body control (Carson et al., 2019; Hasanah et al., 2025; Hinkley et al., 2014).

Gross motor skills in children aged 5–6 years are a fundamental developmental aspect that plays an important role in supporting children's physical readiness to participate in learning activities and actively engage in their social environment. Gross motor skills include a series of basic movement skills involving the large muscles of the body to perform various physical actions. Gross motor skills are defined as fundamental movement skills consisting of three main categories: (1) locomotor skills, such as walking, running, and jumping; (2) object control skills, which involve manipulating objects through movements such as throwing, catching, and kicking; and (3) stability skills, which relate to postural control and both static and dynamic balance (Azzahra et al., 2024; Pangestu et al., 2024; Sutapa et al., 2021). Motor exercises that are specifically designed and actively involve children in physical activities have been proven to contribute positively to improving early childhood gross motor skills, particularly in movement coordination, balance, and mastery of large muscle groups (Faizah et al., 2024; Wang & Zhou, 2024).

The development of gross motor skills in early childhood can be significantly improved through planned and meaningful movement activities, especially when movement is combined with musical stimuli that encourage integration between sound perception and bodily movement responses (Nela et al., 2025; Zhao et al., 2024). Music and dance learning that actively involves children's physical participation has been shown to support the development of movement coordination, balance, and large-muscle control more optimally than spontaneous or unstructured movement activities (Cirelli & Kragness, 2025; Haida et al., 2023). However, in learning practices across many early childhood education institutions, children's gross motor development often remains less than optimal because physical activities and movement experiences have not been systematically designed. Learning practices in early childhood education settings also show that music and dance activities are still often positioned merely as routine or entertainment activities, so their integrative potential in developing children's gross motor skills has not been optimally utilized.

Research shows that movement learning accompanied by music or songs can improve early childhood gross motor skills; however, its implementation in the field is often limited to entertainment or routine activities without focusing on specific developmental goals (Dianti, 2024). In addition, various empirical studies have proven the effectiveness of dance and creative movement programs in improving early childhood gross motor competence (Anggraini & Hasnawati, 2018; Haida et al., 2023). Nevertheless, in practice, many of these activities have not yet been integrated with STEAM components, such as simple science exploration, the use of basic technology, or the mapping of relationships between sound stimuli and movement responses (sound–motion mapping). As a result, music and dance learning in early childhood education has not fully optimized children's sensorimotor integration and creativity, so the potential for strengthening gross motor skills through a more comprehensive and structured STEAM approach remains underutilized in daily learning practices.

The STEAM approach (Science, Technology, Engineering, Arts, and Mathematics) is regarded as an integrative learning paradigm that emphasizes interdisciplinary integration through play, exploration, and meaningful problem-solving activities for children (Raharjo, 2005; Suryaningsih et al., 2025). In early childhood education, STEAM is not only oriented toward concept mastery but also encourages children to construct knowledge through direct experiences involving integrated sensory, cognitive, and motor interactions (Elias et al., 2024; Tabiin, 2020). Studies show that the implementation of STEAM in early childhood education contexts can stimulate children's critical thinking, creativity, and problem-solving skills through multisensory learning experiences that align with early childhood developmental characteristics (Ellizah et al., 2020; Hasibuan et al., 2022). The Arts element in STEAM plays a strategic role as a bridge between thinking processes and bodily expression, because art, particularly music and dance, provides space for children to translate sound stimuli, rhythm, and patterns into movement responses (Gálvez et al., 2026; Lindeman et al., 2013). The integration of this artistic element can be developed more systematically through the sound–motion mapping approach, namely a planned mapping between sound characteristics and movement patterns, so that STEAM learning not only enriches children's aesthetic experiences but also strengthens sensorimotor integration and the development of gross motor skills in early childhood education contexts.

In the context of early childhood education, sound–motion mapping is described as a learning strategy that systematically links sound stimuli with bodily movement, making auditory experiences both a trigger and a driver of motor responses. The integration of sound and motion does not merely present music as background accompaniment, but utilizes rhythm, tempo, and sound patterns to facilitate synchronization between children's auditory perception and movement responses simultaneously, which ultimately improves coordination and gross motor skills (Suriana et al., 2024; Williams et al., 2023). Research shows that structured music and movement activities can help children recognize sound patterns and rhythms through bodily movement responses, serving as a multisensory learning medium that integrates the sense of hearing and motor control to strengthen sensorimotor connections (Françoise & Bevilacqua, 2018; Liu & Ko, 2022). Thus, sound–motion mapping not only trains coordination, balance, and motor rhythm but also provides enjoyable and meaningful learning experiences for young children.

Although various studies have shown that movement learning combined with music and dance improves gross motor skills in early childhood, most of them still treat movement mainly as physical stimulation. Few explicitly bring in the dimensions of science and technology, or the deliberate mapping between sound stimuli and children's movement responses. The STEAM approach in early childhood education has been examined as a holistic and multi-domain learning strategy; however, its implementation is still dominated by science exploration and art-based activities conducted separately, so the potential integration of music and movement has not been optimally utilized. Beyond this, studies that specifically examine the use of the sound–motion mapping approach, namely the systematic mapping between sound characteristics and bodily movement patterns in STEAM-based music and dance learning to develop early childhood gross motor skills, remain very limited, particularly in the context of early childhood education in Indonesia. This condition indicates a research gap that needs to be addressed through the development and testing of a learning model that integrates music, movement, and STEAM principles in a structured manner to strengthen early childhood gross motor development.

Based on this research gap, this study aims to analyze the effect of the STEAM approach with sound–motion mapping on early childhood gross motor development. Specifically, this study examines how the mapping between sound stimuli and movement responses, designed systematically, can improve children's movement coordination, balance, and body control in the context of early childhood education learning. The main contribution of this study lies in presenting an innovative learning approach that integrates the arts elements, namely music and dance, with STEAM principles through multisensory learning experiences. Therefore, this study not only enriches pedagogical practices in early childhood education but also provides an empirical foundation for developing a more holistic and meaningful learning model to support early childhood gross motor development.

What specifically distinguishes sound–motion mapping from general music-and-movement activities is its explicit and systematic pairing of defined auditory characteristics, such as a particular rhythm, tempo, intensity, or sound cue, with predetermined, repeatable movement responses, so that sound functions as a structured motor instruction rather than as background accompaniment. In conventional music-and-movement practice, children typically move freely or imitatively while music plays, and the sound–movement relationship remains loose and incidental. In the sound–motion mapping approach, by contrast, each

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auditory cue is deliberately "mapped" to a specific motor pattern, transforming the activity into a rule-governed sensorimotor task that children can decode, anticipate, and reproduce consistently. Within the STEAM framework, this mapping is what integrates the five domains in a single activity. The Arts provide the musical and movement material, while Science and Mathematics are engaged as children analyze and classify sound properties together with movement patterns, sequences, and counts. Technology comes in through the tools used to generate and shape the sound cues. Engineering appears when children design and gradually refine their own consistent sound–movement "codes." The distinct value of sound–motion mapping, therefore, lies not in adding art to physical activity but in turning an explicit auditory-to-motor rule system into practice, which makes STEAM integration concrete, observable, and reproducible for teachers in early childhood settings.

2. Research Method and Materials

This study employed a quantitative approach using a quasi-experimental design, specifically a non-equivalent control group design. This design was selected because the study was conducted in existing early childhood education classes, making it impossible to randomly assign participants to groups. Schematically, the research design involved two groups, namely an experimental group and a control group, both of which were administered a pretest and a posttest. The experimental group received STEAM-based music and dance instruction using a sound–motion mapping approach, whereas the control group participated in conventional music and dance learning activities. The study population consisted of children aged 5–6 years enrolled at TK Magfira Makassar. The sampling technique employed was purposive sampling, considering the equivalence of age and classroom characteristics. The total sample comprised 24 children, with 12 children assigned to the experimental group and 12 children to the control group.

It should be acknowledged that the sample size of 24 children (12 per group) is small and was drawn from a single early childhood education center. This sample size is consistent with the practical constraints of an intact-class quasi-experiment conducted in an authentic classroom setting, and it is comparable to that of several prior classroom-based studies of movement and dance interventions in early childhood. Nevertheless, a small single-site sample necessarily limits statistical power for detecting smaller effects and, more importantly, restricts the statistical generalizability of the findings to the broader and more diverse population of young children. Accordingly, the results reported here should be interpreted as evidence of the approach's efficacy within this specific context rather than as directly generalizable population estimates, and the limitations arising from sample size and single-site design are addressed explicitly in the Discussion and Conclusion sections, together with recommendations for larger, multi-site replication.

Data were collected through structured observation and gross motor performance tests administered during both the pretest and posttest stages. The research instrument was an early childhood gross motor assessment rubric encompassing indicators of locomotor skills, stability skills, and movement synchronization with sound rhythm and tempo. Each indicator consisted of two assessment items. The indicators were evaluated using a four-point rating scale: excellent (4), good (3), fair (2), and poor (1).

each child was observed and scored individually during the performance tasks following the same standardized procedure for both groups. To maintain consistent scoring across the pre-test and post-test intervals, each of the four rating levels (1 = poor, 2 = fair, 3 = good, 4 = very good) was anchored to explicit, observable behavioral descriptors specified in advance in the rubric, and every child was rated against these same fixed criteria under identical task conditions at both time points, so that scoring depended on the predefined behavioral anchors rather than on the observer's impression at any single session. Nevertheless, the involvement of only one observer meant that inter-rater reliability could not be computed, and this is acknowledged as a methodological limitation of the present study.

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Prior to the main study, the instrument was subjected to validity and reliability testing. Gross motor skill measurement data were analyzed using IBM SPSS Statistics software through descriptive statistical analysis and inferential statistical tests to determine differences and treatment effects between the experimental and control groups. The results of the instrument item validity test are presented in Table 1.

Table 1. Instrument Validity Test

No Item	r-Grain	Sig. (2- tailed)	Test	Conclusion
Item 1	0.71	0.000	Sig. < 0.05	Valid
Item 2	0.66	0.000	Sig. < 0.05	Valid
Item 3	0.74	0.000	Sig. < 0.05	Valid
Item 4	0.62	0.000	Sig. < 0.05	Valid
Item 5	0.70	0.000	Sig. < 0.05	Valid
Item 6	0.61	0.000	Sig. < 0.05	Valid

The results of the reliability testing of the gross motor skills assessment instrument are presented in Table 2.

Table 2. Instrument Reliability Instrumen

Cronbach	N Item
0.79	6

Based on the output presented in the table above, the Cronbach's Alpha coefficient for the six assessment items was 0.79. This value falls within the range of 0.70–0.90, indicating a good level of internal consistency. Therefore, the instrument was considered reliable and suitable for use in the study.

Supporting instruments used in this study included Lesson Plans (LPs) developed for both the experimental and control groups. The lesson plans for the experimental group implemented STEAM-based music and dance learning through a sound–motion mapping approach, whereas the control group followed conventional music and dance learning activities.

2.1. *Data Analysis*

The implementation of STEAM-based music and dance learning using the sound–motion mapping approach in the experimental group was evaluated using learning implementation criteria. These criteria were classified into four categories: very good (76% < percentage ≤ 100%), good (51% < percentage ≤ 75%), fair (26% < percentage ≤ 50%), and poor (0% < percentage ≤ 25%) (Arikunto, 2013).

To describe the level of gross motor skills among children aged 5–6 years, percentage analysis was conducted based on the Criterion-Referenced Assessment (CRA) with a maximum score of 24. The assessment criteria used were as follows:

Table 3. Criteria Classification

Gross Motor Skill Level Intervals (GMSLI%)	Score	Category
(76<GMSLI ≤ 100)	21-24	Very Good
(51<GMSLI ≤ 75)	16-20	Good
(26<GMSLI ≤ 50)	11-15	Fair
(0<GMSLI ≤ 25)	6-10	Poor

The data were presented in the form of tables and histograms displaying the mean, median, mode, standard deviation, variance, range, minimum score, maximum score, total score, and graphical representations to facilitate interpretation. Descriptive statistical analysis in this study was conducted using IBM SPSS Statistics 21.

The normality of the data distribution was first examined using the Shapiro-Wilk test, which is recommended for small sample sizes (n < 50), and the homogeneity of variances was assessed using Levene's test. Because the assumption of normality was not fulfilled for the experimental group, hypothesis testing was performed using the non-parametric Mann-

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Whitney U test to examine the differences between the two independent groups at a significance level of 0.05, complemented by effect size estimates to quantify the magnitude of the group differences.

The difference test was conducted to verify that there was no significant difference in gross motor skills between the experimental and control groups prior to the implementation of the treatment. Meanwhile, the post-test difference test was used to evaluate the effectiveness of STEAM-based music and dance learning through the sound–motion mapping approach.

3. Results and Discussion

3.1. Result

The results of the study indicate that the implementation of STEAM-based music and dance learning through the sound–motion mapping approach was effective in improving the gross motor skills of children aged 5–6 years. Assessment was conducted through structured observations and performance tests covering locomotor skills, stability skills, and movement synchronization with rhythm and sound tempo. The results of the validity and reliability analyses showed that all instrument items possessed adequate levels of validity and reliability. Prior to the intervention, the gross motor skill levels of the experimental and control groups were relatively homogeneous, with no statistically significant differences observed between the two groups.

Following the intervention, the analysis revealed a significant difference in the mean post-test scores of gross motor skills between the experimental and control groups. Children in the experimental group, who participated in STEAM-based music and dance learning through the sound–motion mapping approach, achieved higher gross motor skill scores than those in the control group, who received conventional music and dance instruction. On top of this, observations of the learning implementation indicated that the instructional process in the experimental group was conducted at a very good level, as reflected by the children's active engagement in responding to auditory stimuli through coordinated body movements.

3.1.1. Description of Learning Implementation Observation Data

The implementation of the learning activities was observed to ensure consistency between the planned instructional procedures and their implementation in the classroom. Observations were conducted in both the experimental and control groups. The results of the learning implementation observations are presented in Table 4.

Table 4. Observation Results of Learning Implementation in the Experimental and Control Groups

Group	Learning Implementation Percentage (%)	Category
Experimental	91.53	Very Good
Control	91.54	Very Good

Based on the data presented in Table 4, the implementation of learning activities in both the experimental and control groups was classified as very good.

The finding that learning implementation was classified as very good in both the experimental group (91.53%) and the control group (91.54%) warrants specific interpretation. Rather than indicating a weakness in the design, this near-identical, high implementation fidelity in both conditions indicates that the two groups were taught with comparable instructional quality, consistency, and teacher commitment, and that both lesson plans were delivered as intended. This is methodologically desirable because it helps isolate the treatment. Since the control group also received well-implemented conventional music-and-dance instruction, the substantial post-test difference favoring the experimental group cannot be attributed to differences in delivery quality or teacher effort. It is more plausibly attributable to the distinctive feature of the intervention itself, namely the systematic sound–motion mapping. In this sense, the strong performance of the control condition strengthens rather than weakens the internal validity of the effect. At the same time, the observation instrument used here measured the fidelity of procedural implementation (whether the planned activities were

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carried out) rather than the qualitative pedagogical differences between the two approaches; it was therefore not designed to capture the finer-grained features that distinguish sound–motion mapping from conventional practice. Future studies would benefit from complementary observation tools sensitive to these qualitative process differences, so that the specific mechanisms of the intervention can be documented alongside its measurable outcomes.

3.1.2. Pre-test Data Description

The pre-test results of the experimental group showed a mean gross motor skill score of 8.75 with a standard deviation of 0.754. The lowest score obtained by the children was 8, while the highest score reached 10. Meanwhile, the pre-test results of the control group indicated a mean gross motor skill score of 8.17 with a standard deviation of 1.467. The lowest score obtained was 6, whereas the highest score reached 10. A summary of the pre-test data is presented in Tables 5 and 6.

Table 5. Descriptive Statistics of Pre-test Data for the Experimental Group

Statistics	
	Pre-test Experimental Class
N Valid	12
Missing	0
Mean	8.75
Std. Deviation	.754
Minimum	8
Maximum	10
Sum	105

Table 6. Descriptive Statistics of the Control Group Pre-test Scores

Statistics	
	Pre-test Control Class
N Valid	12
Missing	0
Mean	8.17
Std. Deviation	1.467
Minimum	6
Maximum	10
Sum	98

Information regarding the gross motor skill levels of the study participants at the pre-test stage is presented in Table 7, which provides a detailed overview of the gross motor abilities of children aged 5–6 years prior to the implementation of STEAM-based music and dance learning through the sound–motion mapping approach.

Table 7. Pre-test Results of Gross Motor Skills

Score	Category	Experimental Group		Control Group	
		Frequency	Percentage	Frequency	Percentage
(76< GMSLI≤ 100)	Very Good	0	0%	0	0%
(51< GMSLI≤ 75)	Good	0	0%	0	0%
(26< GMSLI≤ 50)	Fair	0	0%	0	0%
(0< GMSLI ≤ 25)	Poor	12	100%	12	100%
Total		12	100%	12	100%

Table 7 shows that in the experimental group, no children were classified in either the very good or good categories of gross motor skills. All of the children (100%) were categorized as poor. The same pattern was observed in the control group, where no children fell into the very good, good, or fair categories, and all of the children (100%) were likewise classified as poor.

Taken together, these pre-test results show that the gross motor skills of children aged 5–6 years at the pre-test stage, in both the experimental and control groups, were still at a relatively low level and were comparable prior to the implementation of STEAM-based music and dance learning through the sound–motion mapping approach.

3.1.3. Equivalence Test of the Experimental and Control Groups

In this experimental research design, an equivalence test was conducted as a control measure to ensure that the experimental results were not influenced by participants' initial abilities. Prior to selecting the appropriate statistical test, the underlying distributional assumptions were examined, and the results are presented as follows.

3.1.3.1. Normality Test

The following section presents a summary of the pre-test normality test results for both the experimental and control groups.

Table 8. Normality Test Results for Pre-test Scores

Tests of Normality

Class		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Score	Pre-test Experimental	.257	12	.028	.807	12	.011
	Pre-test Control	.144	12	.200	.907	12	.197

a. Lilliefors Significance Correction

Table 8 shows that the pre-test gross motor skill scores of the experimental group yielded a Shapiro-Wilk significance value (Sig.) of 0.011, which is smaller than 0.05, indicating that the data were not normally distributed. Meanwhile, the pre-test scores of the control group produced a Shapiro-Wilk significance value of 0.197, which is greater than 0.05, indicating a normal distribution. The Shapiro-Wilk test was used as the primary reference given the small sample size ($n = 12$ per group). Because the normality assumption was violated in the experimental group, a non-parametric approach was adopted for the equivalence test.

3.1.3.2. Homogeneity Test

The following section presents a summary of the homogeneity test results for the pre-test scores of the experimental and control groups.

Table 9. Homogeneity Test Results for Pre-test Scores

Test of Homogeneity of Variances

Homogenitas Pre-test

Levene Statistic	df1	df2	Sig.
5.279	1	22	.031

The results of the homogeneity test using Levene's Test showed a significance value of 0.031 ($p < 0.05$). This finding indicates that the variances of the pre-test gross motor skill scores in the experimental and control groups were not homogeneous. Together with the violation of normality in the experimental group, this result reinforced the decision to employ the non-parametric Mann-Whitney U test for the group comparison.

3.1.3.3. Mann-Whitney U Test of Pre-test Scores

The following section presents a summary of the mean pre-test scores for the experimental and control groups.

Table 10. Results of the Mann-Whitney U Test for Pre-test Scores

Group	N	Mean Rank	Sum of Ranks
Experimental	12	13.88	166.50
Control	12	11.13	133.50

Mann-Whitney U = 55.500; Wilcoxon W = 133.500; Z = -0.988; Asymp. Sig. (2-tailed) = 0.338

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Based on Table 10, the Mann-Whitney U test yielded U = 55.500 with Z = -0.988 and a significance value of 0.338 ($p > 0.05$). Therefore, the null hypothesis (H_0) was accepted, and the alternative hypothesis (H_1) was rejected. These results indicate that there was no significant difference in the pre-test gross motor skill scores between the experimental and control groups. In other words, the two groups were equivalent prior to the implementation of the intervention.

3.1.3.4. Descriptive Statistics of Post-test Data

The post-test results of the experimental group showed a mean gross motor skill score of 22.33 with a standard deviation of 1.231. The lowest score obtained was 21, while the highest score reached 24. Meanwhile, the post-test results of the control group indicated a mean gross motor skill score of 13.58 with a standard deviation of 1.881. The lowest score obtained was 11, whereas the highest score reached 16, achieved by three children.

A summary of the descriptive statistical analysis of the post-test gross motor skill scores is presented in Tables 11 and 12.

Table 11. Descriptive Statistics of the Experimental Group Post-test Scores

Statistics		
		Post-test Experimental Class
N	Valid	12
	Missing	0
Mean		22.33
Std. Deviation		1.231
Minimum		21
Maximum		24
Sum		268

Table 12. Descriptive Statistics of the Control Group Post-test Scores

Statistics		
		Control Group Post-test
N	Valid	12
	Missing	0
Mean		13.58
Std. Deviation		1.881
Minimum		11
Maximum		16
Sum		163

Information regarding the gross motor skill levels of the study participants in the post-test phase is presented in Table 13, which provides an overview of the gross motor abilities of children aged 5–6 years after participating in STEAM-based music and dance learning through the sound–motion mapping approach.

Table 13. Post-test Results of Gross Motor Skills

Score Range	Category	Experimental Group		Control Group	
		Frequency	Percentage	Frequency	Percentage
($76 < GMSLI \leq 100$)	Very Good	12	100%	0	0%
($51 < GMSLI \leq 75$)	Good	0	0%	3	25%
($26 < GMSLI \leq 50$)	Fair	0	0%	9	75%
($0 < GMSLI \leq 25$)	Poor	0	0%	0	0%
Total		12	100%	12	100%

Table 13 presents the distribution of children's gross motor skill levels at the post-test stage. In the experimental group, all of the children (100%) were classified in the very good category. These results indicate a substantial improvement compared with the pre-test condition, in which all of the children were classified in the poor category.

In contrast, the gross motor skills of children in the control group were predominantly classified as fair (75%), followed by good (25%), and no children reached the very good

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category. These findings suggest that STEAM-based music and dance learning implemented through the sound–motion mapping approach was more effective in improving the gross motor skills of young children than conventional music and dance instruction.

3.1.4. Effectiveness of STEAM-Based Music and Dance Learning Through the Sound–Motion Mapping Approach

Following the administration of both the pre-test and post-test, hypothesis testing was conducted to examine the difference between the two groups. Prior to selecting the statistical test, the required distributional assumptions were assessed, and the results are presented as follows.

3.1.4.1. Normality Test

A summary of the normality test results for the post-test scores of the experimental and control groups is presented below.

Table 14. Normality Test Results for Post-test Scores

Tests of Normality

Class		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Score	Post-test Experimental	.194	12	.200	.845	12	.032
	Post-test Control	.151	12	.200	.906	12	.189

a. Lilliefors Significance Correction

As shown in Table 14, the post-test gross motor skill scores of the experimental group yielded a Shapiro-Wilk significance value of 0.032, which was smaller than 0.05 ($p < 0.05$), indicating that the post-test scores of the experimental group were not normally distributed. Meanwhile, the control group obtained a Shapiro-Wilk significance value of 0.189, which was greater than 0.05 ($p > 0.05$), indicating that the post-test scores of the control group were normally distributed.

Based on these results, the normality assumption required for parametric statistical analysis was not satisfied for the experimental group. Therefore, the difference between the two groups was examined using the non-parametric Mann-Whitney U test, which does not require the assumption of normality.

3.1.4.2. Homogeneity of Variance Test

The following section presents a summary of the homogeneity test results for the post-test scores of the experimental and control groups.

Table 15. Results of the Homogeneity of Variance Test for Post-test Scores

Test of Homogeneity of Variances

Homogenitas Post-test

Levene Statistic	df1	df2	Sig.
3.031	1	22	.096

The results of the homogeneity test using Levene's Test yielded a significance value of 0.096 ($p > 0.05$). This finding indicates that the variances of the post-test gross motor skill scores in the experimental and control groups were homogeneous. Nevertheless, because the normality assumption was not satisfied for the experimental group, hypothesis testing was conducted using the non-parametric Mann-Whitney U test.

3.1.4.3. Hypothesis Testing

The hypotheses proposed in this study were as follows:

H_0: There is no significant difference in gross motor skills based on the instructional treatment applied.

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$\mathbf{H_1}$: There is a significant difference in gross motor skills based on the instructional treatment applied.

Table 16. Results of the Mann-Whitney U Test for Post-test Scores

Group	N	Mean Rank	Sum of Ranks
Experimental	12	18.50	222.00
Control	12	6.50	78.00

Mann-Whitney U = 0.000; Wilcoxon W = 78.000; Z = -4.182; Asymp. Sig. (2-tailed) = 0.000

Based on Table 16, the Mann-Whitney U test yielded U = 0.000 with Z = -4.182 and a significance level of 0.000 ($p < 0.05$). Therefore, the null hypothesis was rejected. The value of U = 0 reflects a complete separation between the two distributions, in which every child in the experimental group obtained a higher post-test score than every child in the control group. These results indicate that there was a highly significant difference in gross motor skills between the children in the experimental group and those in the control group.

To quantify the magnitude of the observed difference, effect sizes were calculated. Because the hypothesis test was non-parametric, the non-parametric effect sizes are reported as the primary metrics. The Mann-Whitney U test result corresponded to a rank-based effect size of r = 0.85 and a rank-biserial correlation of r_rb = 1.00, both indicating a very large effect. These indices were derived directly from the test statistic using the standard formulas $r = Z / \sqrt{N}$, where Z is the standardized Mann-Whitney statistic and N is the total sample size, and $r\_rb = 1 - (2U) / (n_1 \times n_2)$, where U is the Mann-Whitney U value and n_1 and n_2 are the two group sizes. For the post-test comparison (Z = -4.182, N = 24, U = 0, $n_1 = n_2 = 12$), these formulas yield r = 0.85 and r_rb = 1.00. For descriptive comparability with the wider literature only, an equivalent parametric Cohen's d was also computed from the group descriptive statistics (d = 5.50, 95% CI [3.75, 7.26]; Hedges' g = 5.32 after correction for small-sample bias); this value is reported for cross-study reference rather than as the primary effect size, since the parametric assumptions underlying d were not fully met. In contrast, the pre-test comparison produced only a small effect size (r = 0.20), further confirming the initial equivalence of the two groups. These results indicate that the difference in gross motor skills between the experimental and control groups was statistically significant and, importantly, practically meaningful, although effect size estimates obtained from small samples have limited precision, as reflected in the width of the confidence interval.

Overall, STEAM-based music and dance learning implemented through the sound–motion mapping approach was effective in improving children's gross motor skills compared with the conventional learning approach applied in the control group. This result is reflected in the mean post-test gross motor skill score of the experimental group, which reached 22.33, substantially higher than the mean score of 13.58 obtained by the control group.

Following the administration of both pre-test and post-test assessments in the two groups, the overall findings of the study confirm that the implementation of STEAM-based music and dance learning through the sound–motion mapping approach was effective in optimizing the gross motor development of young children.

3.2. Discussion

This discussion examines the implementation of STEAM-based music and dance learning through the sound–motion mapping approach, the level of gross motor skills among young children, and the effectiveness of this approach in promoting gross motor development. These three aspects represent the main findings of the study, encompassing an analysis of the learning process, an overview of children's gross motor skill levels before and after the intervention, and an evaluation of the effectiveness of STEAM-based music and dance learning implemented through sound–motion mapping.

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Furthermore, the findings of this study are discussed in relation to relevant theories and previous research findings to provide support for and validation of the results obtained.

3.2.1. The Implementation of STEAM-Based Music and Dance Learning Through the Sound–Motion Mapping Approach

STEAM-based music and dance learning is an instructional process that integrates the elements of Science, Technology, Engineering, Arts, and Mathematics through structured rhythmic movement activities. This approach provides meaningful learning experiences for young children by connecting auditory stimuli with motor responses, a process known as sound–motion mapping. Through the systematic mapping of sound and movement, children are encouraged to synchronize rhythm, tempo, and musical dynamics with coordinated body movements, thereby facilitating the optimal development of gross motor skills.

The intervention administered to the experimental group consisted of eight STEAM-based music and dance learning sessions implemented through the sound–motion mapping approach. Each session was conducted for approximately 30–35 minutes, three times per week. The learning activities emphasized the integration of auditory stimuli and movement patterns to develop children's ability to associate rhythm, tempo, and auditory signals with coordinated motor responses.

At the beginning of each session, children participated in a brief warm-up activity involving rhythmic clapping and simple locomotor movements. This activity was designed to prepare children physically, improve their attentional focus, and enhance their readiness to engage in the subsequent learning tasks.

The core learning activities were designed progressively to develop children's ability to map auditory stimuli to specific movement patterns. During the first and second sessions, the teacher introduced basic rhythmic patterns through hand clapping and the use of simple rhythmic instruments. Children were instructed to perform specific movements whenever they heard particular sounds, allowing them to become accustomed to associating auditory stimuli with motor responses. In the third session, the learning focus shifted to the exploration of slow, moderate, and fast tempos. The teacher played children's songs with varying tempos, and the children were encouraged to adjust their movements according to the changes in speed, thereby enhancing their timing accuracy and responsiveness to tempo variations.

This is in line with what was reported by Ulfah & Kamtini, (2023), who emphasized that dance activities serve both as a medium for aesthetic expression and as an effective means of developing young children's gross motor skills through structured and repetitive movement sequences. This perspective highlights the importance of designing rhythmic movement activities that are systematic rather than random, enabling children to gradually develop and refine movement patterns. In the present study, this structure was operationalized through the systematic mapping of specific sounds to particular body movements. As a result, whenever children heard the same auditory cue, they were able to respond with consistent and coordinated movements.

This finding is further supported by the study of Liya & Katoningsih, (2022), which found that well-structured dance instruction significantly improves gross motor skills in young children. Their study emphasized that dance provides a structured movement experience that directly enhances coordination, balance, and body control, all of which are essential components of gross motor development.

The use of music as a stimulus in movement-based learning has received empirical support from Rosalina et al., (2023), who found that illustrative music is effective in enhancing children's movement skills. Music with clear rhythmic characteristics provides temporal cues that help children coordinate their movements, making the learning process more structured

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and meaningful. This finding directly supports the sound–motion mapping approach implemented in the present study, in which music functions not merely as background accompaniment but as a primary stimulus that guides and shapes children's movement patterns. In a related vein, Wakulu & Priyanti, (2025) reported that systematically designed music-accompanied exercise programs significantly improve the motor skills of young children, highlighting that the structured integration of music into physical movement activities facilitates gross motor development through rhythm stimulation and movement synchronization.

During the fourth and fifth sessions, the learning activities focused on the development of structured movement patterns. Children followed simple dance sequences organized into eight-count movement patterns and were gradually encouraged to create their own "movement codes" based on three types of sounds provided by the teacher, such as hand claps, foot stomps, and instrument beats. This activity reflected weaving in STEAM principles, particularly the Arts and Engineering components, as children were guided to design consistent, structured, and repeatable sound–movement patterns.

Research by Suriana et al., (2024), conducted in the context of Zapin Melayu creative dance adapted for children aged 5–6 years, demonstrated that structured traditional dance activities effectively stimulate gross motor development through the repetition of rhythmic movement patterns. Similar findings were reported by Hasanah et al., (2025), whose classroom action research utilizing the traditional plate dance found that consistent participation in rhythmic dance activities improved children's coordination and balance. Likewise, Nurlaela et al., (2025) reinforced this argument by showing that rhythmic gymnastics is an effective instructional strategy for promoting gross motor development in early childhood, particularly in strengthening coordination, balance, and movement flexibility. Collectively, these findings provide strong empirical support for movement-based learning approaches that integrate rhythm and music, such as the sound–motion mapping approach employed in the present study, as an effective means of fostering gross motor development in young children.

The sixth and seventh sessions emphasized the development of movement synchronization and timing accuracy through freeze dance games and movement pathway activities involving zigzag, circular, and straight-line patterns accompanied by music with a stable tempo. Children were challenged to move, stop, accelerate, or decelerate their movements in response to changes in rhythm, allowing coordination, balance, and body control to be observed more comprehensively. In the final session, children performed a short dance lasting approximately 30 seconds accompanied by music with a consistent rhythm as a final assessment of movement synchronization and timing accuracy.

The learning outcomes showed that the integration of STEAM-based music and dance learning through the sound–motion mapping approach significantly enhanced children's gross motor skills. The systematic mapping of sound and movement provided strong sensorimotor stimulation, as children simultaneously processed auditory stimuli and coordinated corresponding body movements. This finding is consistent with sensorimotor development theory, which posits that the integration of sensory input and motor activity plays a crucial role in strengthening coordination and movement synchronization during early childhood. All of these interventions were administered exclusively to the experimental group, whereas the control group participated in regular instructional activities without the implementation of sound–motion mapping or STEAM-based music and dance integration.

The creative dimension of STEAM-based dance learning is also supported by the findings of Ardiyanti et al., (2025), who reported that creative dance activities incorporating elements of cultural identity positively influence the motor development of young children. Their study emphasized that dance activities involving creative exploration improve movement skills and, beyond that, encourage deeper cognitive and emotional engagement. This perspective aligns with the principles of the sound–motion mapping approach applied in the present study, in

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which children were not merely required to imitate predetermined movements but were also encouraged to design their own movement patterns in response to auditory stimuli, thereby creating a learning experience that was both constructive and creative.

3.2.2. *Effectiveness of STEAM-Based Music and Dance Learning Through the Sound–Motion Mapping Approach*

Our results indicate that STEAM-based music and dance learning implemented through the sound–motion mapping approach was effective in improving the gross motor skills of children aged 5–6 years. This conclusion is supported by the highly significant difference observed between the post-test scores of the experimental and control groups ($p = 0.000 < 0.05$). The experimental group achieved a mean post-test score of 22.33, substantially higher than the control group, which obtained a mean score of 13.58. Furthermore, all of the children (100%) in the experimental group were classified in the very good category, whereas most children in the control group remained in the fair category (75%), with the remainder in the good category (25%). This pattern suggests that combining music and dance through the sound–motion mapping approach provides more effective stimulation for gross motor development than conventional music and dance instruction.

The effectiveness of this approach can be explained through the mechanism of integration between auditory stimuli and motor responses that occurs throughout the learning process. In sound–motion mapping activities, children do not merely listen to sounds or music passively; rather, they actively associate auditory characteristics, such as rhythm, tempo, intensity, and sound patterns, with specific body movements. When children perceive changes in rhythm or tempo, they are required to adjust the speed, direction, and pattern of their movements accordingly. This process promotes movement synchronization, defined as the ability to coordinate body movements in response to external stimuli. Through repeated practice in linking auditory cues with movement responses, children gradually develop improved coordination, balance, body control, and temporal accuracy, all of which are fundamental components of gross motor competence.

These findings are consistent with Piaget's sensorimotor development theory, which posits that children's motor development emerges through active interactions between sensory perception and physical action. In the sound–motion mapping approach, children engage in learning experiences that simultaneously involve listening, observing, processing information, and performing body movements. The integration of these processes strengthens the connection between sensory and motor systems, resulting in improved movement coordination. In other words, the enhancement of gross motor skills observed in the experimental group can be attributed not only to participation in physical activities but also to the active processing of auditory information, which is subsequently translated into coordinated motor responses.

From the perspective of rhythmic entrainment theory, the findings can also be explained by humans' natural tendency to synchronize bodily movements with perceived rhythmic patterns. Rhythm serves as a temporal cue that assists children in organizing the timing, speed, and sequence of movements in a more structured manner. When children move in response to musical beats or tempo changes, the brain automatically synchronizes auditory perception with motor activity. This synchronization process contributes to improvements in balance, bilateral coordination, postural control, and movement accuracy. Therefore, music functions not merely as an accompaniment to learning activities but as a primary stimulus that facilitates the development of motor skills more effectively.

The effectiveness of this approach is further strengthened by the integration of STEAM principles within the learning activities. The Science component is reflected in children's exploration of differences in sound, tempo, and rhythm. The Technology component is represented through the use of audio devices as sources of auditory stimulation. Engineering is incorporated when children design or construct movement patterns based on specific

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sound codes. The Arts component is embodied in the music and dance activities that constitute the core of the learning process, while the Mathematics component is reflected in children's understanding of patterns, movement sequences, counting, and rhythm. The integration of these five domains creates a rich learning experience that draws on several senses together that improves gross motor skills while also promoting cognitive development, creativity, problem-solving abilities, and self-regulation skills.

From a holistic child development perspective, Brian, (2022) described the existence of cascading effects in gross motor development, whereby the acquisition of fundamental motor skills during early childhood continuously influences children's cognitive, social, and academic development. In the context of the present study, these cascading effects were evident in the way gross motor enhancement through sound–motion mapping improved children's movement abilities and, in addition, supported the development of auditory information processing, attentional control, and self-regulation. Veldman et al., (2023) further reinforced this argument by demonstrating significant associations between gross motor skills and self-regulation as well as executive functioning in preschool children. Their findings suggest that gross motor-based interventions yield holistic benefits that extend beyond the physical domain alone. These results underscore the importance of strengthening gross motor skills during early childhood as a long-term investment in children's overall development.

Marinšek & Denac, (2020) specifically examined rhythmic skills in early childhood and found that the ability to respond to and internalize rhythmic patterns constitutes an important foundation for both motor and musical development. In the present study, rhythm training through sound–motion mapping provided children with direct opportunities to actively respond to rhythmic patterns through bodily movement, thereby enhancing not only rhythmic sensitivity but also temporal movement coordination. Similarly, the work of Sulistiyowati et al., (2022), which explored the mapping between human vocalizations and dance movements, provides strong theoretical support for the sound–motion mapping approach. Their findings indicate that the relationship between sound and movement is natural and can be utilized pedagogically to promote sensorimotor coordination in children. This theoretical foundation reinforces the notion that sound–motion mapping is not merely an artificial methodological innovation but rather an approach grounded in valid biological and cognitive mechanisms.

The study conducted by Wu et al., (2025), which examined dance-based STEAM education in a kindergarten in Shanghai, represents one of the most relevant studies parallel to the present research. Their findings revealed that an interdisciplinary approach integrating dance with scientific principles within a STEAM framework can simultaneously enhance children's motor skills, creativity, and scientific understanding. The study emphasized that integrating dance into STEAM education should not be seen merely as adding an artistic component to a science-oriented curriculum. Rather, dance works as a pedagogical strategy in its own right. It draws on the distinctive qualities of body movement as a medium for exploration, problem-solving, and creative expression, which suits the way young children learn.

A key similarity between their study and the present research lies in the use of structured movement activities as a medium for integrating multiple developmental domains into a cohesive learning experience. In both contexts, movement-based learning serves as more than a means of physical engagement; it also acts as a vehicle for fostering cognitive, creative, and socio-emotional development through interdisciplinary and experiential learning processes.

Rika et al., (2024) demonstrated that structured collaborative learning strategies can significantly improve the gross motor skills of young children. Their findings highlighted that clear instructional structures, systematic guidance, and continuous feedback are key factors distinguishing effective learning from mere exposure to physical activities. This perspective

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is reflected in the design of the present study, which implemented a sequence of progressively structured learning sessions, from the introduction of basic rhythmic patterns to more complex movement synchronization tasks. Through this gradual progression, children were able to systematically develop their gross motor skills within a supportive and well-organized learning environment.

Mazeed, (2023) further reinforced these findings from a clinical perspective, reporting that systematically designed music-based programs effectively enhance motor skills among children with special needs. This evidence suggests that the potential of music as a motor stimulus is universal, as it is grounded in biological mechanisms involving neural entrainment between auditory perception and motor responses. Such findings provide additional theoretical support for the effectiveness of the sound–motion mapping approach implemented in the present study, which relies on the synchronization of auditory cues and bodily movement to facilitate motor development.

Empirical evidence reported by Polak & Sikora, (2022) showed that dance training conducted consistently and regularly leads to significant improvements in children's motor skills. Their study emphasized that the positive effects of dance on motor development require structured and repeated exposure rather than isolated or occasional participation. This finding supports the research design adopted in the present study, which involved eight systematically organized learning sessions with progressively increasing movement intensity and complexity. Similarly, Darussalam et al., (2025), found that fun game-based learning effectively enhances gross motor skills among children in early elementary education. Their findings underscore the importance of presenting motor-learning activities in engaging and motivating formats. This principle was reflected in the present study through the implementation of sound–motion mapping activities embedded within exploratory and creative play-based experiences, enabling children to develop motor skills while maintaining high levels of enjoyment and engagement throughout the learning process.

A systematic review conducted by Dewi et al., (2025) identified several key factors influencing gross motor development in early childhood, including environmental stimulation, the quality of movement experiences provided, and the consistency of instructional programs. The findings of the present study directly support these factors by demonstrating that the sound–motion mapping approach provides a rich learning environment and high-quality movement experiences through the integration of auditory, visual, and kinesthetic stimuli within a unified learning experience. From the perspective of teachers as facilitators, Rahmawati & Suryadi, (2025) reported that teachers' theoretical and pedagogical understanding of gross motor development is a critical determinant of the quality of stimulation provided to children. This finding suggests that the success of the sound–motion mapping approach depends not only on the design of learning activities but also on teachers' capacity to understand the developmental objectives underlying the intervention. Consequently, continuous professional development for early childhood educators should be considered an essential component of the long-term implementation of this approach.

The present results align with those of Anggraini & Hasnawati, (2018) and Haida et al., (2023), who reported that dance and creative movement activities effectively enhance gross motor skills in young children. The present study also supports the findings of Dianti, (2024), who demonstrated that movement activities accompanied by music contribute to improvements in children's coordination and motor skills. The results also reinforce the work of Williams et al., (2023), which showed that the integration of music and bodily movement enhances movement synchronization and motor coordination through the close relationship between auditory perception and motor responses.

Despite these similarities, the present study differs in several important respects from previous research. Most earlier studies utilized music or dance primarily as media for movement stimulation without systematically linking specific auditory characteristics to

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corresponding movement patterns. In addition, previous approaches generally focused on artistic or movement activities in isolation and did not comprehensively integrate STEAM components. In contrast, the present study employed a sound–motion mapping approach that explicitly established systematic connections between auditory stimuli and children's movement responses. Consequently, children were not merely encouraged to move in response to music; rather, they learned to recognize sound patterns, interpret auditory information, and translate that information into structured and meaningful movements.

The novelty of this study lies in the integration of STEAM-based music and dance learning with the sound–motion mapping approach within the context of early childhood education. This research extends beyond examining the effectiveness of music or dance alone in promoting gross motor development by introducing a multisensory instructional model that simultaneously connects auditory, cognitive, and motor domains. The approach offers a novel contribution to early childhood educational practice by optimizing gross motor skills through active, creative, and integrated learning experiences. Notably, this study represents one of the few empirical investigations specifically examining the application of sound–motion mapping in Indonesian early childhood education settings. As such, it provides an important foundation for the future development of more innovative STEAM-based learning models and interventions.

3.2.3. Practical Implications, Scalability, and Generalizability

Beyond demonstrating a statistically significant effect within a single classroom, these findings also invite consideration of how the sound–motion mapping approach might be adopted across different early childhood education systems. One practical strength of the approach is that it requires few resources. It relies only on commonly available materials such as recorded or live music, simple rhythmic instruments (claps, stomps, and percussion), and open floor space, rather than specialized technology or costly equipment. This makes it plausibly transferable to resource-constrained settings, including public and rural early childhood centers, where elaborate STEAM infrastructure is often unavailable. The core mechanism, which maps particular auditory cues to particular movement responses, needs very little in the way of materials and can be carried out with whatever sound sources a center already has.

At the same time, scalability depends on more than materials. Realistic adoption across varied contexts requires attention to teacher capacity, curricular fit, and cultural responsiveness. Because the effectiveness of the approach rests on teachers' ability to design coherent sound–movement "codes" and to sequence them progressively, teacher training is the primary enabling condition for scale-up. This is consistent with Rahmawati & Suryadi, (2025), who identified educators' pedagogical understanding of gross motor development as a decisive determinant of stimulation quality. A viable scaling pathway would therefore embed sound–motion mapping within existing in-service teacher professional development, supported by ready-to-use lesson templates and exemplar sound–movement mappings that reduce preparation burden while preserving the systematic pairing that defines the approach.

The approach is also culturally adaptable, which supports its transferability across different educational traditions. Because the mapped auditory stimuli can be drawn from any musical repertoire, the model can be localized using each community's own songs, rhythms, and traditional movement forms. In the Indonesian context, for example, the approach aligns naturally with the Fase Fondasi of the Kurikulum Merdeka, which foregrounds play-based, contextual, and holistic learning, and it can be enacted using regional musical and dance traditions as the mapped stimuli. This same logic generalises internationally: educational systems with differing curricular frameworks and cultural approaches to early childhood can retain the underlying auditory-to-motor mapping principle while substituting locally meaningful music and movement, allowing the model to be implemented without importing a fixed, culturally specific set of activities.

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4. Conclusion

Based on the findings of this study, it can be concluded that STEAM-based music and dance learning implemented through the sound–motion mapping approach has a significant positive effect on the gross motor skills of children aged 5–6 years. The results of the statistical analysis revealed a highly significant difference between the gross motor skill performance of children in the experimental and control groups following the intervention ($p < .001$). The experimental group achieved a higher mean post-test score than the control group, indicating that the intervention was effective in enhancing children's gross motor development. The observed improvement can be attributed to the integration of STEAM-based music and dance activities through sound–motion mapping, which systematically connects auditory stimuli with motor responses. Learning activities involving rhythm, tempo, and sound patterns encouraged children to synchronize their movements, regulate timing, improve body coordination, maintain balance, and control their movements more effectively. Therefore, the integration of STEAM-based music and dance learning through the sound–motion mapping approach was found to significantly enhance movement synchronization and motor timing in young children by giving children active, meaningful learning experiences.

From a practical perspective, the findings have important implications for instructional practices in early childhood education settings. First, early childhood educators should develop the competencies necessary to design and implement music and dance activities that systematically integrate STEAM principles rather than using music and dance merely as entertainment or routine classroom activities. As emphasized by Rahmawati & Suryadi, (2025), a deep understanding of gross motor developmental objectives is essential for providing effective stimulation to young children. Second, gross motor activities should be designed progressively and supported by auditory stimuli as a medium for motor development, as this approach has been shown to promote movement synchronization and body coordination more effectively than conventional instructional methods. Third, early childhood education centers should provide learning environments rich in multisensory stimulation, including visual, auditory, and kinesthetic experiences, to support optimal and meaningful movement-based learning.

At the policy level, these findings point to several concrete recommendations for integrating sound–motion mapping into national and regional early childhood curricula. First, curriculum authorities could position structured, music-based gross motor activity as an explicit learning experience within existing early childhood frameworks rather than leaving it to incidental practice. In Indonesia, this could be articulated within the Fase Fondasi of the Kurikulum Merdeka as a contextual, play-based means of supporting motor development, and comparable curricular anchors exist in other national systems. Second, given that teacher capacity is the main determinant of implementation quality, ministries and training institutions could incorporate sound–motion mapping into pre-service and in-service teacher education, accompanied by openly available lesson templates and exemplar mappings that lower the barrier to adoption. Third, policy support could encourage the localization of the approach through regional musical and dance repertoires, enabling cultural relevance while preserving the systematic auditory-to-motor mapping principle. Because the approach is low-cost and materially minimal, such policies are feasible even in resource-constrained districts, offering an equitable pathway to strengthen early childhood gross motor development at scale. These recommendations are offered as actionable directions; however, their effectiveness at the system level should be evaluated through larger, multi-site studies such as those proposed above.

The post hoc power analysis (two-tailed, $n = 12$ per group) indicated statistical power exceeding .99, suggesting that the study had sufficient power to detect the very large effect observed. Nevertheless, small samples yield imprecise effect size estimates, as reflected in the wide confidence interval; therefore, the magnitude of the effect should be interpreted with caution and verified in future studies with larger samples. Related to this, the observational data were collected by a single observer; although a structured rubric with explicit behavioral descriptors was used to minimize subjectivity, the absence of inter-rater reliability testing remains a limitation, and future studies are recommended to involve multiple trained observers. A further consideration is that the single observer was not blind to group allocation, since the researcher also delivered the intervention; combined with the exceptionally clear separation between groups, this raises the possibility of unintentional observer bias, and future studies should employ independent, blinded assessors to rule out this threat to validity. The very large effect size obtained (Cohen's d = 5.50) is also atypical for educational interventions. Given the small sample, the short eight-session duration, and the wide confidence interval, this value is likely to overestimate the true magnitude of the effect. It should therefore be read as an indication of a strong effect within this study rather than as a precise, generalizable estimate. In addition, the intervention was conducted over only eight sessions, which does not allow for the examination of the long-term effects of the approach on children's gross motor development. As noted by Brian, (2022), gross motor development produces cascading effects across multiple developmental domains; therefore, longitudinal studies are needed to explore the broader and sustained impacts of sound–motion mapping interventions.

Future research should involve larger and more diverse samples, encompassing a wider range of geographical and sociocultural contexts. Subsequent studies should also investigate the long-term effects of sound–motion mapping on other developmental domains, including cognitive, language, and socio-emotional development. Future researchers may also explore variations of the sound–motion mapping approach using diverse Indonesian traditional musical repertoires and examine their relationships with rhythmic literacy, creativity, and self-regulation in early childhood, as suggested by Dewi et al., (2025) and Veldman et al., (2023). Such investigations would contribute to a deeper understanding of the potential of multisensory STEAM-based learning approaches in promoting holistic child development.

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