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The Effectiveness of STEAM-Based Learning in Enhancing Early Childhood Creativity in the Deep Learning Era

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The digital era, marked by rapid advances in artificial intelligence and deep learning technologies, has transformed the paradigm of early childhood education, creating a need for learning models that effectively foster creativity as a key twenty-first-century competency. This study aimed to analyze the effectiveness of the Science, Technology, Engineering, Art, and Mathematics (STEAM) learning model in enhancing early childhood creativity through project-based activities integrating science, technology, art, and simple engineering concepts. A quantitative approach with a quasi-experimental non-equivalent control group design was employed involving 30 children aged 5–6 years, consisting of 15 children in the experimental group and 15 children in the control group from a kindergarten. The experimental group participated in STEAM-based learning, while the control group received conventional instruction. The findings revealed that the STEAM learning model was effective in improving children's creativity. MANCOVA analysis indicated that pretest scores had a significant effect on posttest outcomes ($p < 0.001$), whereas parents' educational background showed no significant influence on creativity development or intervention outcomes. These results demonstrate that interactive, collaborative, and project-based STEAM learning encourages children to become more active, enthusiastic, innovative, and creative in expressing their ideas. Therefore, the STEAM learning model is recommended as an effective strategy for implementing the Merdeka Curriculum and strengthening creativity and critical thinking skills in early childhood education.

Keywords: *Early Childhood, Deep Learning, Creativity.*

Abstrak

Era digital yang ditandai oleh perkembangan kecerdasan buatan dan deep learning telah mengubah paradigma pendidikan anak usia dini, sehingga diperlukan model pembelajaran yang mampu menumbuhkan kreativitas sebagai salah satu kompetensi penting abad ke-21. Penelitian ini bertujuan menganalisis efektivitas model pembelajaran Science, Technology, Engineering, Art, and Mathematics (STEAM) dalam meningkatkan kreativitas anak usia dini melalui kegiatan berbasis proyek yang mengintegrasikan sains, teknologi, seni, dan rekayasa sederhana. Penelitian menggunakan pendekatan kuantitatif dengan desain quasi-experiment non-equivalent control group design yang melibatkan 30 anak usia 5–6 tahun, terdiri atas 15 anak pada kelompok eksperimen dan 15 anak pada kelompok kontrol di salah satu taman kanak-kanak. Kelompok eksperimen mengikuti pembelajaran berbasis STEAM, sedangkan kelompok kontrol memperoleh pembelajaran konvensional. Hasil penelitian menunjukkan bahwa model pembelajaran STEAM efektif dalam meningkatkan kreativitas anak usia dini. Analisis MANCOVA mengungkapkan bahwa skor pretest berpengaruh

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signifikan terhadap posttest (p < 0,001), sedangkan tingkat pendidikan terakhir orang tua tidak memberikan pengaruh yang signifikan terhadap perkembangan kreativitas maupun hasil intervensi pembelajaran. Temuan ini menunjukkan bahwa pembelajaran STEAM yang interaktif, kolaboratif, dan berorientasi proyek mampu mendorong anak menjadi lebih aktif, antusias, inovatif, serta kreatif dalam mengekspresikan ide. Oleh karena itu, model STEAM direkomendasikan sebagai strategi implementatif Kurikulum Merdeka untuk memperkuat kreativitas dan kemampuan bernalar kritis anak usia dini.

Kata Kunci: Anak Usia Dini, Deep Learning, Kreativitas, STEAM.

INTRODUCTION

The rapid advancement of digital technologies has transformed educational systems across the world. Developments in artificial intelligence (AI), deep learning, and digital learning environments have reshaped how knowledge is delivered, accessed, and constructed within educational settings (Ahmed & Yadav, 2023). Educational institutions increasingly integrate technology into teaching and learning processes to support the development of competencies required in the twenty-first century. These changes have influenced not only learning resources and instructional methods but also the skills that learners need to develop in order to participate effectively in an increasingly complex society (Alkhatib et al., 2023).

Creativity has emerged as one of the most important competencies in contemporary education. Educational frameworks consistently identify creativity as a key skill that supports innovation, problem-solving, adaptability, and lifelong learning. The development of creativity is particularly important during early childhood because this developmental period provides the foundation for future cognitive, social, and emotional growth (Ng et al., 2024a). Children who are encouraged to explore, experiment, imagine, and express ideas freely are more likely to develop flexible thinking and innovative problem-solving abilities (Ng et al., 2024b). Early educational experiences therefore play a critical role in supporting the emergence of creative potential.

Despite its importance, creativity remains insufficiently developed in many early childhood education settings. Instructional practices often emphasize knowledge acquisition, routine activities, and teacher-directed learning experiences. Such approaches may limit opportunities for children to investigate ideas, engage in experimentation, and generate original solutions. The increasing demand for creativity-oriented learning has encouraged educators to explore instructional approaches that actively engage children in meaningful and authentic learning experiences. This need has become more apparent as educational systems seek to prepare learners for a rapidly changing technological landscape.

One approach that has received considerable attention is Science, Technology, Engineering, Arts, and Mathematics (STEAM) education. STEAM extends the STEM framework by incorporating arts as an essential component of learning, creating

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opportunities for children to combine analytical reasoning with creative expression (Janga et al., 2023). The approach integrates multiple disciplines within a unified learning experience and encourages learners to investigate problems from different perspectives. Educational activities within STEAM environments frequently involve inquiry, experimentation, design, collaboration, and reflection, all of which contribute to the development of higher-order thinking skills (Mashala et al., 2023; Qureshi et al., 2023).

Researchers have reported positive outcomes associated with STEAM implementation across various educational contexts. Previous studies indicate that STEAM-based learning can support the development of creativity, critical thinking, innovation, and problem-solving abilities among learners (Popescu et al., 2024). The interdisciplinary nature of STEAM encourages children to connect ideas across domains while engaging in hands-on learning experiences. Project-based activities provide opportunities for learners to construct knowledge through exploration and active participation rather than passive reception of information. These characteristics make STEAM particularly relevant for fostering creativity during early childhood.

The growing integration of digital technologies into educational environments has introduced new possibilities for STEAM implementation. Advances associated with the deep learning era have expanded access to interactive learning resources, adaptive technologies, and personalized educational experiences (Cao et al., 2023). Technology-enhanced learning environments can support children's engagement by providing dynamic opportunities for exploration and discovery. Digital tools also enable learners to interact with information in ways that encourage experimentation, creativity, and collaboration (Ren et al., 2023). These developments highlight the potential relationship between technological innovation and creativity development in early childhood education.

Deep learning technologies have attracted increasing attention because of their capacity to support adaptive and personalized learning experiences. Educational applications powered by deep learning can provide individualized feedback, adjust learning challenges, and accommodate diverse learning needs (Stade et al., 2024). Such capabilities may create conditions that encourage children to explore ideas more freely and engage in creative problem-solving processes. Educational researchers have emphasized the importance of examining how emerging technologies can be integrated into pedagogical approaches that support holistic child development (Bañuelos et al., 2023; Yan et al., 2024).

Although the benefits of STEAM have been widely discussed, several challenges continue to affect its implementation in early childhood education. Teachers often report difficulties related to instructional design, technological integration, and the availability of appropriate learning resources (Korzynski et al., 2023). The implementation of STEAM in classrooms serving young children remains uneven, and empirical evidence concerning its effectiveness continues to vary across contexts. These

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challenges suggest the need for further investigation into how STEAM-based learning can be implemented effectively to support children's creativity.

Research examining STEAM within early childhood education has increased in recent years; however, important gaps remain. Existing studies have frequently focused on the general implementation of STEAM or on technology-enhanced learning as separate areas of inquiry. Limited attention has been directed toward understanding the effectiveness of STEAM-based learning for fostering creativity among young children within educational contexts influenced by contemporary technological developments (Li et al., 2024; Chakraborty et al., 2024). Additional evidence is needed to clarify the contribution of STEAM-based learning to creativity development during early childhood and to inform instructional practices in rapidly evolving educational environments.

This study examines the effectiveness of STEAM-based learning in enhancing creativity among children aged 5–6 years in the deep learning era. The study focuses on project-based learning activities that integrate science, technology, engineering, arts, and mathematics into meaningful classroom experiences. Creativity is examined through the dimensions of fluency, flexibility, originality, and elaboration. The study investigates whether children who participate in STEAM-based learning demonstrate higher creativity outcomes than children who experience conventional instruction. The findings are expected to contribute empirical evidence that supports the development of innovative and creativity-oriented practices in early childhood education.

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental design with a non-equivalent control group design. This design was selected because random assignment of children was not feasible within the natural classroom setting while still allowing comparison between groups receiving different instructional treatments (Cooper, 2023). Both groups completed a pretest to assess their initial levels of creativity. The experimental group received STEAM-based learning interventions, whereas the control group participated in conventional teacher-centered learning activities. Following a four-week intervention period, both groups completed a posttest to evaluate changes in creativity. This design was considered appropriate for maintaining ecological validity while examining the effectiveness of STEAM-based learning in enhancing early childhood creativity.

Participants

The participants consisted of 30 children aged 5–6 years enrolled in a kindergarten in West Sumatra, Indonesia. The sample was divided into an experimental group (n = 15) and a control group (n = 15). Participants were selected using purposive sampling based on criteria relevant to the research objectives (Messeri & Crockett, 2024). The inclusion criteria were: (1) children aged 5–6 years, (2) adequate

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communication and motor skills, (3) regular participation in classroom group-learning activities, and (4) written parental consent for participation. In addition, two classroom teachers were involved as facilitators during the implementation of STEAM-based learning activities, while the researcher served as an observer throughout the study. The participant characteristics ensured that all children were developmentally capable of engaging in the planned learning activities.

Instrumentation

The primary instrument used in this study was an Early Childhood Creativity Observation Sheet developed based on Torrance's Theory of Creativity and the Torrance Tests of Creative Thinking (TTCT). The instrument measured four major dimensions of creativity: fluency, flexibility, originality, and elaboration (Dou et al., 2023). Each indicator was assessed using a four-point Likert scale ranging from 1 (Not Yet Developed) to 4 (Very Well Developed). In addition to the observation sheet, field notes and documentation of children's products, including drawings, constructions, and simple experimental projects, were collected as supporting data. To ensure instrument quality, content validity was evaluated by three experts in early childhood education, developmental psychology, and educational technology. Inter-rater reliability was established by comparing observations from two independent raters to ensure scoring consistency and objectivity.

Data Collection Procedure

Data collection was conducted in three stages: preparation, implementation, and evaluation. During the preparation stage, the researcher coordinated with school administrators and teachers, explained the study objectives and procedures, obtained parental consent, and conducted a pilot test of the research instruments to ensure clarity and contextual appropriateness (Zhai et al., 2024). During the implementation stage, the experimental group participated in STEAM-based learning activities three times per week for four weeks, with each session lasting approximately 60 minutes. Learning activities were designed as project-based experiences integrating science, technology, engineering, arts, and mathematics, such as constructing mini bridges from ice-cream sticks, building balloon-powered cars, and conducting color-mixing experiments. Teachers acted as facilitators who guided children through exploration, observation, collaboration, and problem-solving processes. Meanwhile, the control group continued to receive conventional thematic instruction. Throughout the intervention period, creativity observations, field notes, and activity documentation were systematically collected. At the end of the intervention, a posttest using the same instrument as the pretest was administered to both groups.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics, including means, standard deviations, and gain scores,

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were calculated to describe creativity levels before and after the intervention. Prior to hypothesis testing, assumptions of normality and homogeneity of variance were examined to determine the suitability of parametric analyses (Lee, 2024). To evaluate differences between groups while controlling for pretest scores, Multivariate Analysis of Covariance (MANCOVA) was employed. This analysis was selected because it allowed the examination of treatment effects on posttest creativity outcomes while accounting for baseline differences between participants. Statistical significance was determined at the 0.05 level. In addition, qualitative data obtained from field notes and children's project documentation were analyzed thematically to provide contextual insights into children's creative behaviors and learning experiences during the intervention.

Quality Assurance and Ethical Considerations

Several measures were implemented to ensure research quality and ethical compliance. Prior to data collection, ethical approval was obtained from the relevant institutional authority, and written informed consent was secured from all parents or legal guardians. Participants and their families received comprehensive information regarding the study’s objectives, procedures, benefits, and their right to withdraw from the study at any time without consequences. Participant confidentiality was protected through the use of anonymous identification codes, and all data were stored securely. The principle of non-maleficence was strictly observed by ensuring that all STEAM activities were safe, developmentally appropriate, and conducted using child-friendly materials. To strengthen reliability and reduce observer bias, classroom observations were conducted by two independent raters, and inter-rater agreement was assessed throughout the study. Furthermore, learning sessions were documented and periodically reviewed with classroom teachers to ensure consistency in the implementation of STEAM-based learning activities. These procedures were undertaken to ensure that the study produced valid, reliable, and ethically sound findings regarding the effectiveness of STEAM-based learning in enhancing early childhood creativity in the deep learning era.

RESULTS AND DISCUSSION

Results

Descriptive Analysis of Children's Creativity Scores

This study involved 30 children aged 5–6 years who were divided equally into an experimental group and a control group. The experimental group participated in STEAM-based learning activities for six weeks, while the control group received conventional thematic instruction. Children's creativity was assessed using indicators adapted from Torrance's creativity framework, including fluency, flexibility, originality, and elaboration. The descriptive results are presented in Table 1.

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Table 1. Comparison of Children's Creativity Scores

Learning Group	N	Mean Pretest	Mean Posttest	Difference (Post–Pre)	Percentage Increase (%)
Experimental (STEAM)	15	60.4	87.6	+27.2	45.0
Control (Conventional)	15	59.8	72.3	+12.5	20.9

As shown in Table 1, both groups demonstrated relatively similar pretest scores, indicating comparable initial creativity levels before the intervention. Following the six-week instructional period, the experimental group achieved a substantial increase of 27.2 points (45.0%), whereas the control group showed an increase of only 12.5 points (20.9%). These findings suggest that STEAM-based learning was more effective in enhancing children's creativity than conventional thematic instruction. The magnitude of improvement observed in the experimental group indicates that interdisciplinary and project-based learning experiences provided greater opportunities for creative expression and problem-solving. These findings support the effectiveness of STEAM in promoting creativity among young children in the deep learning era.

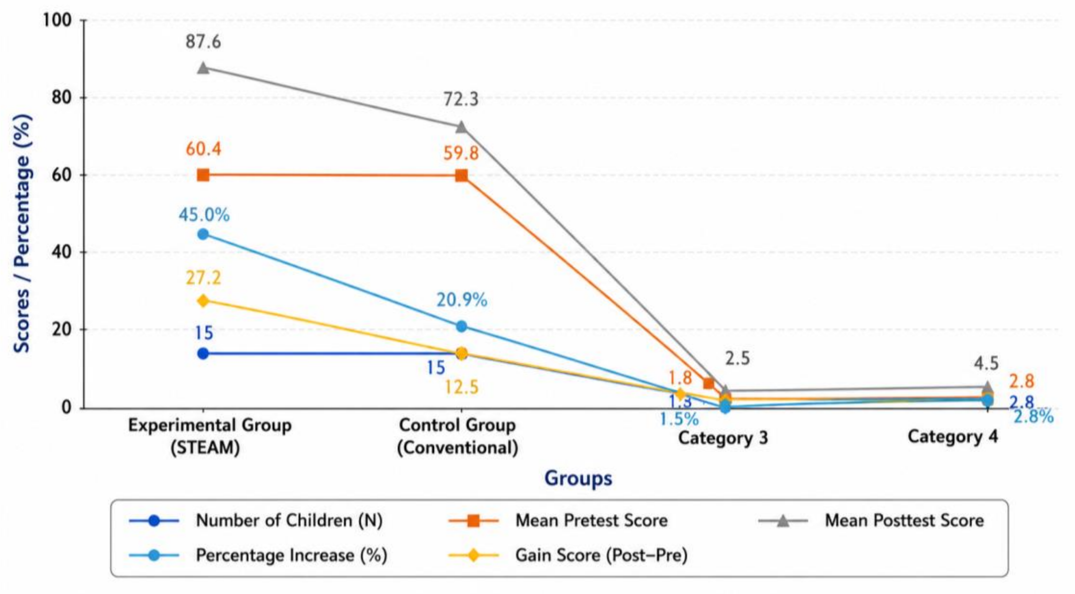

Figure 1. Comparison of Pretest and Posttest Creativity Scores Between Groups

The graphical representation further illustrates the considerable difference in creativity gains between the two groups. Children exposed to STEAM-based learning consistently demonstrated higher posttest scores than those who participated in conventional instruction. The visual trend confirms that the intervention produced meaningful improvements in children's creative development.

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Percentage of Creativity Improvement

To provide a clearer picture of the effectiveness of the intervention, creativity gains were categorized according to their percentage increase.

Table 2. Percentage Improvement in Children's Creativity

Learning Group	N	Mean Pretest	Mean Posttest	Difference	Percentage Increase (%)	Category
Experimental (STEAM)	15	60.4	87.6	+27.2	45.0	Very High
Control (Conventional)	15	59.8	72.3	+12.5	20.9	Moderate

The experimental group demonstrated a creativity increase of 45.0%, which falls within the very high category. In contrast, the control group achieved a moderate increase of 20.9%. The comparison indicates that children who engaged in STEAM-based activities experienced creativity gains that were approximately twice those of children in conventional learning environments. These descriptive findings are consistent with the subsequent inferential analyses, which revealed statistically significant differences between the two groups ($t = 4.87$, $p = .001$).

Normality Test

Before conducting hypothesis testing, data normality was examined using the Kolmogorov–Smirnov and Shapiro–Wilk tests.

Table 3. Results of the Normality Test

Learning Group	Test Type	N	Kolmogorov-Smirnov Sig.	Shapiro-Wilk Sig.	Interpretation
Experimental (STEAM)	Pretest	15	0.200	0.356	Normal Distribution
Experimental (STEAM)	Posttest	15	0.178	0.215	Normal Distribution
Control (Conventional)	Pretest	15	0.126	0.291	Normal Distribution
Control (Conventional)	Posttest	15	0.147	0.224	Normal Distribution

All significance values exceeded 0.05, indicating that the creativity scores were normally distributed. The normality assumption was therefore satisfied, allowing the use of parametric statistical procedures for subsequent analyses.

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Homogeneity Test

Variance homogeneity was assessed using Levene's Test.

Table 4. Results of the Homogeneity Test

Test Type	Levene Statistic	df1	df2	Sig.	Interpretation
Pretest	0.214	1	28	0.647	Homogeneous
Posttest	1.327	1	28	0.259	Homogeneous

The significance values for both pretest and posttest scores were greater than 0.05, confirming homogeneity of variance between the experimental and control groups. These results indicate that the assumption of equal variances was met.

Independent Samples t-Test

An independent samples t-test was conducted to examine differences in posttest creativity scores between the two groups.

Table 5. Independent Samples t-Test Results

Learning Group	N	Mean	SD	t	df	Sig. (2-tailed)	Interpretation
Experimental (STEAM)	15	87.6	4.8				
Control (Conventional)	15	72.3	6.0	4.87	28	0.001	Significant

The analysis yielded a t-value of 4.87 with a significance level of p = .001. Since the probability value was below the 0.05 threshold, a statistically significant difference existed between the experimental and control groups. The mean posttest score of the experimental group (M = 87.6) was substantially higher than that of the control group (M = 72.3), indicating that STEAM-based learning produced stronger creativity outcomes than conventional instruction. Consequently, the research hypothesis was supported.

Discussion

The findings demonstrate that STEAM-based learning significantly enhanced early childhood creativity. Children who participated in interdisciplinary project-based activities achieved substantially higher creativity gains than those who experienced conventional thematic instruction. The increase of 45.0% observed in the experimental group confirms that STEAM provides an effective pedagogical framework for fostering creativity among children aged 5–6 years. These findings support previous evidence suggesting that integrated learning experiences encourage higher levels of engagement, exploration, and creative thinking (Darmawansah et al., 2023; Ng et al., 2023).

The improvement observed across the dimensions of fluency, flexibility, originality, and elaboration indicates that STEAM activities stimulated multiple aspects of creative thinking simultaneously. Children generated more ideas, demonstrated greater adaptability when solving problems, produced more original responses, and elaborated their ideas in greater detail. These outcomes align with Torrance's theory of

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creativity and support previous findings that interdisciplinary learning environments promote divergent thinking and creative problem-solving (Marques et al., 2024; Van Noorden & Perkel, 2023).

The results are also consistent with previous studies reporting positive effects of STEAM implementation on children's creativity. Putri and Rahma (2020) found that science experiments and artistic activities enhanced originality and elaboration among young learners. Similar conclusions were reported by Yuliani et al. (2021) and Nugroho (2022), who observed that STEAM-based learning contributed to higher-order thinking skills and creative performance. The present findings strengthen this body of evidence by demonstrating the effectiveness of STEAM within educational environments increasingly influenced by digital technologies and deep learning applications.

Technology integration appears to have contributed to the effectiveness of the intervention. Children interacted with digital drawing applications, interactive videos, and AI-supported educational tools that enriched learning experiences and connected abstract concepts with concrete exploration activities. These findings support the argument that digital technologies can enhance creativity when integrated into meaningful pedagogical frameworks (Omrani et al., 2024). Technology served not merely as a learning aid but as a medium through which children explored ideas, tested solutions, and expressed creativity.

The findings can also be interpreted through Vygotsky's social constructivist perspective. STEAM activities encouraged collaboration, discussion, and shared problem-solving among children. Such interactions created opportunities for scaffolding within the Zone of Proximal Development, enabling children to develop creative competencies through social engagement (Fergus et al., 2023; Chen et al., 2023). Creativity emerged not only from individual exploration but also from collaborative learning processes supported by peers and teachers.

Teacher facilitation played an important role in the success of the intervention. Rather than functioning as the primary source of knowledge, teachers guided exploration, encouraged questioning, and supported children's experimentation. This finding is consistent with previous research emphasizing the importance of facilitative teaching approaches within project-based and STEAM-oriented learning environments (Eggmann et al., 2023; Hassija et al., 2024). Effective STEAM implementation requires teachers to create meaningful learning experiences that integrate science, technology, engineering, arts, and mathematics in developmentally appropriate ways. The findings also have practical relevance for the implementation of the Merdeka Curriculum in Indonesia. The emphasis on creativity, critical reasoning, project-based learning, and learner autonomy aligns closely with the principles of STEAM education (Syamala et al., 2023; Biswas, 2023). The present study provides empirical evidence supporting the use of STEAM as a practical instructional strategy for strengthening creative competencies among young children.

Several limitations should be acknowledged. The intervention was conducted over a relatively short period of six weeks, preventing an examination of long-term

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effects. The study was also limited to a single kindergarten, which may restrict the generalizability of the findings. Future studies could involve larger samples, multiple educational settings, and longitudinal designs to examine the sustainability of creativity development through STEAM-based learning.

The findings indicate that STEAM-based learning represents an effective approach for enhancing creativity among young children in the deep learning era. The integration of interdisciplinary learning experiences, collaborative problem-solving, project-based activities, and technology-supported exploration created conditions that promoted children's creative development. These results contribute to the growing evidence supporting STEAM education as a valuable strategy for preparing young learners to thrive in increasingly complex and technology-rich environments.

CONCLUSION

This study demonstrates that STEAM-based learning is effective in enhancing creativity among children aged 5–6 years in the deep learning era. Children who participated in STEAM activities showed significantly higher creativity outcomes than those who experienced conventional instruction, as reflected in a 45% increase in creativity scores. The findings indicate that project-based learning integrating science, technology, engineering, arts, and mathematics effectively promotes fluency, flexibility, originality, and elaboration, which are key dimensions of creativity. Interactive and collaborative learning experiences encouraged children to explore ideas, solve problems, and express themselves creatively while fostering curiosity, scientific attitudes, and collaborative skills. The integration of digital technologies further enriched learning experiences by providing opportunities for visualization, experimentation, and innovation. These findings support the growing evidence that STEAM-based learning represents a valuable pedagogical approach for early childhood education and aligns with the objectives of the Merdeka Curriculum in developing creative and critical learners. The study contributes empirical evidence highlighting the potential of STEAM to support holistic child development and prepare young learners for future challenges in increasingly technology-driven educational environments.

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DECLARATION ON THE USE OF ARTIFICIAL INTELLIGENCE (AI)

The authors used ChatGPT (OpenAI) exclusively to improve the language quality, grammar, and readability of this manuscript. The AI tool was also used to assist in organizing references and enhancing the overall presentation of the manuscript. It

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was not used to generate research data, design the experimental procedures, develop research instruments, perform statistical analyses, interpret research findings, or formulate scientific conclusions. All aspects of the study, including the research design, implementation of the intervention, data collection, statistical analysis, interpretation of results, and conclusions, were developed, verified, and approved entirely by the authors. The authors accept full responsibility for the accuracy, originality, and integrity of the final published manuscript.

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