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TEACHERS' AND PRINCIPALS' UNDERSTANDING OF STEAM IN EARLY CHILDHOOD EDUCATION UNDER THE MERDEKA CURRICULUM: A CASE STUDY

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Abstract: *The successful implementation of Science, Technology, Engineering, Arts, and Mathematics (STEAM) in early childhood education (ECE) requires educators and school leaders to possess a sound understanding of STEAM concepts and pedagogical practices. This study aimed to explore the understanding of STEAM learning held by a kindergarten teacher and a school principal in an ECE setting implementing the Merdeka Curriculum. Using qualitative research, data were collected through classroom observations, in-depth interviews, and document analysis at a kindergarten in Pati Regency, Central Java. Data were analyzed using the Miles and Huberman model. The findings revealed differences in participants' understanding of STEAM, particularly in science, technology, and mathematics. The teacher tended to view science as observation, technology as electronic devices, and mathematics as number recognition, whereas the principal demonstrated a broader understanding. These differences influenced classroom practices, which remained largely teacher-centered and provided limited opportunities for children's exploration, critical thinking, and creativity, indicating that STEAM implementation had not yet fully reflected the child-centered principles promoted by the Merdeka Curriculum. The study highlights the importance of strengthening teachers' conceptual and pedagogical understanding of STEAM and enhancing school leaders' instructional role in supporting meaningful, developmentally appropriate learning experiences that foster curiosity, problem-solving skills, and holistic child development.*

Keywords: *STEAM, ECE, Understanding, Teacher, Principal*

A. Introduction

The integration of Science, Technology, Engineering, Arts, and Mathematics, known as STEAM, has recently attracted widespread global attention across both academic research and classroom application (Perignat & Katz-Buonincontro, 2019, as cited in Wang & Lin, 2025). Responding to this global demand, Indonesia's current Early Childhood Education (ECE) framework has formalized these competencies through the implementation of the *Merdeka Curriculum*, which grants educators the autonomy to design contextual learning experiences based on children's needs (Badan Standar, Kurikulum, dan Asesmen Pendidikan, 2022). Underpinning this curriculum are three primary learning outcome elements that drive instructional planning, one of which is Basic Literacy and STEAM. While the broader element reinforces language and early literacy skills alongside STEAM learning, this study narrows its empirical focus specifically to the STEAM dimensions.

STEAM in the context of the ECE curriculum in Indonesia is designed to prompt children to ask questions and cultivate curiosity about surrounding phenomena. Through this approach, children are encouraged to construct knowledge independently through processes of exploration, analysis, decision-making, and the evaluation of how systems function (Munawar et al., 2019). This methodology aligns with the characteristics of learning in ECE, which should be active, concrete, and engaging, providing space for children to experiment and learn from direct experience.

Margorini and Rini (2019) assert that STEAM learning offers several advantages, including a significant impact on children's reasoning abilities, particularly in critical thinking and scientific literacy. However, several obstacles continue to hinder the effective implementation of STEAM in ECE settings in Indonesia. Agusniatih and Muliana (2022) identified challenges in which ECE teachers frequently rely on conventional approaches, such as using worksheets for assignments. Children are often tasked with science activities that involve coloring, tracing letters or numbers, and writing. While these activities may develop fine motor skills, they fail to reflect the essence of STEAM, which should focus on exploration, collaboration, and problem-solving. As a result, student engagement in STEAM learning diminishes.

Based on the observations conducted at Kindergarten X (pseudonym used for confidentiality) in Pati Regency, Central Java, several issues were identified in the implementation of STEAM for 5–6-year-olds in Group B. In science instruction, for example, children were merely asked to complete worksheets by coloring and pasting images of plant parts. This one-way activity provides a limited opportunity for active exploration. Similar issues were observed in mathematics instruction. The teacher focused solely on rote memorization of numbers displayed on the wall and writing figures on the whiteboard. This approach fails to stimulate curiosity, reasoning, or critical thinking through exploratory activities, as advocated by Margorini and Rini (2019).

The success of any educational program depends heavily on the extent to which those who are involved understand their roles. In the context of ECE, teachers and school principals play a strategic role in ensuring that learning programs are effective and child-centered. However, most current research focuses only on teachers (e.g., Azizah & Ilise, 2025; Mandira et al., 2024; Qomariyah & Qalbi, 2021). This is a significant gap because principals' ideas and leadership styles usually shape the methods teachers implement in the classroom. This connection between leadership and teaching is especially important for STEAM learning. Therefore, based on the preliminary observation in the X kindergarten, it is interesting to explore further the understanding of the teacher of class B and the school principal regarding STEAM learning in the class. This study aims to explore the teachers' and principals' understanding of STEAM learning in ECE. This understanding serves as a preliminary step toward optimizing children's STEAM learning.

B. Method

This study employed a field research design using a qualitative approach. This approach was selected because it enables researchers to gain an in-depth understanding of the phenomenon under investigation in a natural, contextualized setting.

The research was conducted at a kindergarten located in Pati Regency, Central Java. The site was selected because the institution had begun to adopt the STEAM approach in its daily instructional practices. The research participants consisted of the Kindergarten

B classroom teacher and the school principal. These participants were chosen due to their central roles in instructional planning and implementation within the institution. The classroom teacher is directly responsible for implementing STEAM-based learning in the classroom, while the principal plays a key role in policy-making and program supervision.

Data were collected through classroom observations, in-depth interviews, and document analysis. Classroom observations were conducted directly during learning activities to obtain first-hand insights into how the STEAM approach was planned and implemented in the teaching–learning process. Observational data also enabled the researcher to examine the consistency between the practices and interview findings.

In-depth interviews were conducted with the classroom teacher and the school principal to explore their understanding of STEAM learning. All interviews were conducted face-to-face at the school with participants' consent. Although the researcher prepared guiding questions, these were not used as rigid instruments. Follow-up questions were posed based on participants' responses to obtain more comprehensive, in-depth information about their understanding of STEAM learning.

In addition to observations and interviews, documentation was used as supporting data to strengthen the research findings. The documentation included lesson plans, children's worksheets, and photographs of learning activities. These documents provided authentic evidence of the implementation of STEAM-based learning and contributed to data credibility through source and technique triangulation. The researchers obtained permission from the school before taking documentation.

The collected data were analyzed using the qualitative data analysis model from Miles and Huberman (1994), which consists of four stages: data collection, data reduction, data display, and conclusion drawing/verification. The analysis was conducted iteratively and progressively to ensure a comprehensive and in-depth interpretation of the data.

The data collection stage involved conducting in-depth interviews with the Kindergarten B teacher and the school principal, observing STEAM learning activities, and gathering supporting documentation. Interview data consisted of participants' interpretations of the STEAM concept and its components. Observational data were used to examine how such understandings were reflected in classroom practices, while documentation served as supporting evidence for those practices.

The data reduction stage focused on participants' conceptual understanding of each STEAM. Interview data were transcribed, selected, and coded according to the five core STEAM categories: science, technology, engineering, arts, and mathematics. At this stage, the researchers identified how each participant (the principal and teacher) interpreted and conceptualized each STEAM component. Observational data were also reduced to identify instructional tendencies that reflected participants' understandings, such as whether science was interpreted primarily as observation, technology as electronic devices, or mathematics as number recognition. Data not directly related to STEAM understanding were excluded to maintain analytical focus.

The data display stage involved organizing the reduced data into systematic and comprehensible formats. Data were presented in two primary forms. First, Table 1 presents a comparison of the principals' and teachers' understanding of each STEAM component, based on coded interview data, highlighting differences among participants. Second, Table 2 presents observed STEAM learning activities in the classroom, illustrating how participants' conceptual understanding was enacted in instructional practice.

The final stage, conclusion drawing and verification, involved interpreting patterns that emerged from the data displays. At this stage, the researchers concluded that there were similarities and differences in the principals' and teachers' understanding of STEAM components, particularly in science, technology, and mathematics. They identified the implications of these differences for classroom instructional practices.

Through these four stages of analysis, the data were processed systematically, enabling the findings to be presented comprehensively and rigorously despite the small scale of this study and the limited number of participants. The overall data analysis process is illustrated in Figure 1.

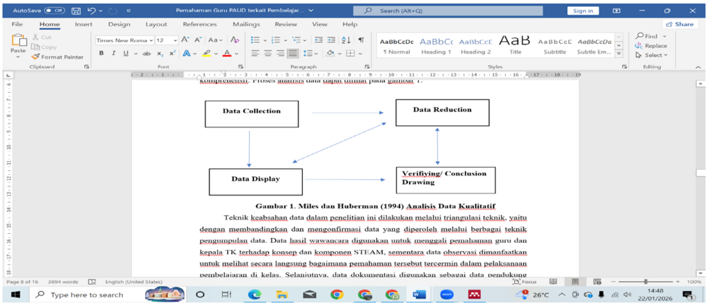


Figure 1. Miles and Huberman (1994) Qualitative Data Analysis

Data trustworthiness in this study was ensured through triangulation, which involved comparing data obtained from multiple data-collection techniques, including interviews, observations, and documentation. Through this cross-validation process across data collection methods, the researchers were able to assess the consistency of the information obtained, to enhance the trustworthiness of the research findings, as suggested by Sugiyono (2022).

C. Result and Discussion

Based on the interviews conducted, the teacher and the principal of Kindergarten X demonstrated differing levels of understanding of the STEAM approach, particularly in science, technology, and mathematics. A more detailed description of teachers' and the principal's understanding of STEAM is presented in Table 1.

Table 1. Principal's and Teacher's Understanding of STEAM

STEAM Component	Principal	Teacher
Science	Learning through observation of the child's surrounding environment and conducting experiments or simple investigations	Learning through observation of the surrounding environment

Technology	Using tools available in the child's environment to support children in completing tasks	The use of electronic devices or tools in the learning process
Engineering	Children's ability to operate tools in their environment to construct something, such as arranging blocks to form a house	Children's ability to use the tools available in their environment
Arts	Expressing children's creativity and imagination through activities such as coloring, painting, drawing, and batik-making	Children's ability to express imagination or creativity through activities such as painting, drawing, and batik-making
Mathematics	Introducing children to concepts of numbers, measurement, classification, and pattern-making	Introducing number concepts to children

Based on Table 1, which presents the understanding of the principal and teacher at Kindergarten X regarding STEAM learning, differences in their understanding are evident, particularly in the areas of science, technology, and mathematics. The teacher tended to interpret science merely as activities involving observation of the surrounding environment, to view technology as limited to electronic devices, and to understand mathematics solely as the introduction of number concepts. This limited view of mathematics was explicitly reflected in the teacher's description of classroom activities and in the interview.

> "For STEAM learning in my kindergarten, it is done through a project that can combine these five fields of knowledge, such as what was done before the ecoprint, which is making crowns from jackfruit leaves; for mathematics, children count the number of jackfruit leaves that have been made into a crown." (Teacher of Class B, personal communication).

This example demonstrated that, while the teacher successfully created hands-on, contextual projects, their understanding of the underlying mathematical component remains limited. By focusing exclusively on counting leaves, the teacher misses valuable opportunities to embed broader mathematical concepts, such as making a leaf crown, which involves geometry (leaf shapes), measurement (fitting the crown to a child's head), and pattern-making. In ECE, mathematics should encompass a wide range of mathematical concepts rather than being restricted to number and counting (M. Hasbi & Rahmawati, 2020).

Similarly, technology should be understood more broadly as any form of human-made tools or objects that facilitate human activities, rather than being restricted to electronic devices alone (D. M. Hasbi, 2021). With such limited understanding, the teacher in Kindergarten X will likely face difficulties in designing and implementing STEAM learning in a comprehensive and meaningful manner. This finding highlights the importance of strengthening teachers' capacity to develop a holistic understanding of STEAM concepts so that classroom implementation aligns with the developmental goals of ECE in the *Merdeka Curriculum*.

In contrast, the findings further indicated that the principal's understanding of STEAM components was generally broader than that of the Kindergarten B classroom teacher. The principal was able to explain STEAM components in a more integrated manner, such as describing science as encompassing both observation and experimentation, and mathematics as including measurement, patterns, and classification. This broader capacity was demonstrated in the interview transcripts, where the principal could break down an ecoprint batik-making activity to cover all five interdisciplinary components of STEAM.

> "The ecoprint batik activity in this STEAM-based learning covers all five STEAM components. In science, children are introduced to leaf shapes and the colors those leaves produce. For technology, children use wooden blocks. Engineering involves how children use wooden blocks to strike leaves, producing color. For art, children are given the freedom to arrange the leaves creatively. For mathematics, children count the number of leaves." (Principal of Kindergarten X, personal communication).

Komara et al. (2024) emphasize that successful implementation depends on the teacher's level of program comprehension. A robust understanding enables teachers to design, execute, and evaluate learning appropriately. Therefore, the role of the principal is crucial not only as an institutional manager, but also as an instructional leader who can guide, facilitate, and enhance teachers' capacity to understand and consistently apply the STEAM under the *Merdeka Curriculum* for ECE.

Strengthening this teaching capacity at the ECE level is vital in addressing Indonesia's broader educational challenges. Results from the Programme for International Student Assessment (PISA), an international assessment framework managed by the OECD (Organization for Economic Co-operation and Development) that measures the reading, mathematical, and scientific literacy of 15-year-old students worldwide, indicate that the proficiency of Indonesian students in mathematics and science remains below the international average. In the 2022 PISA test, Indonesian students achieved a mean score of 366 in mathematics and 383 in science. These results placed Indonesia 69th out of more than 80 participating nations, ranking within the bottom 12. In ASEAN, Indonesia ranked only 6th among the eight participating ASEAN countries (Prasastisiwi, 2024).

The underperformance of Indonesia in PISA, particularly in science and mathematics, suggests that student competencies in these domains have not yet been developed to their full potential. This situation underscores the necessity of systematically strengthening science and mathematics instruction from the earliest stages of education, beginning with improving ECE teachers' competence in STEAM.

To contextualize this need, the STEAM learning activities observed at Kindergarten X in this study are presented in Table 2. It demonstrated how the five STEAM components were integrated into some activities for children. Each component, science, technology, engineering, arts, and mathematics, was implemented through activities related to nature-based themes, one of which was the ecoprint batik-making process.

Table 2. STEAM Learning Activities

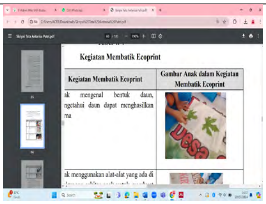
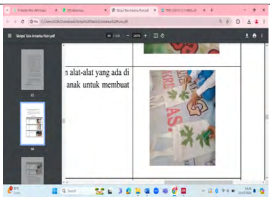
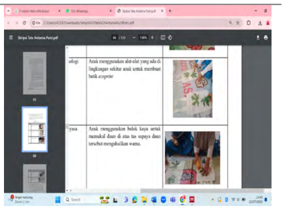
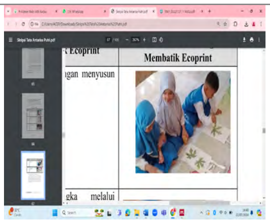
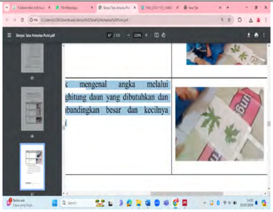
STEAM Component	Activity	Documentation
Science	Children identify different leaf shapes.	
Technology	Children use blocks to create ecoprint batik.	
Engineering	Children use wooden blocks to pound leaves onto a bag so that the leaves release their color.	
Arts	Children create leaf patterns on a bag	
Mathematics	Children learn numbers by counting leaves and comparing the sizes of big and small leaves	

Table 2 showed that STEAM learning activities at Kindergarten X largely reflect the integrative principle that characterizes this approach. One of the strengths of the implementation at Kindergarten X was the use of natural materials, such as leaves, in learning activities. The use of materials readily available in children's surroundings indicates teachers' awareness of the importance of integrating STEAM learning with local contexts or everyday objects familiar to children.

Wahidah Fauziah (2022) emphasize that the use of materials from the surrounding environment not only supports children's cognitive and motor development, but also plays an important role in fostering children's connection with their environment. This is particularly important because early childhood is a critical stage for exploring identity and developing social relationships. Through direct interaction with natural objects, children learn to recognize, appreciate, and feel a sense of belonging to their environment. Thus, this approach is not only relevant to the STEAM principle, which emphasizes interdisciplinary connections, as reflected in the acronym itself, but also helps develop environmental awareness from an early age.

However, Table 2 also revealed limitations in providing opportunities for children to think critically and creatively and to develop curiosity. Although learning activities involved natural materials, the teacher tended to direct the process, for example, by determining the shapes and types of leaves the children would use. This suggests that the activities were more teacher-centered than child-centered. This finding is consistent with the study by Maiyah et al. (2024) which reports that some teachers tend to intervene quickly when children appear to experience difficulties, rather than allowing them sufficient time and opportunity to seek solutions independently. In fact, problem-solving and creative thinking skills can only develop when children are given opportunities to explore, make choices, and face challenges.

In the context of STEAM learning, overly guided approaches may limit the development of meaningful learning experiences. This aligns with the early findings of Azizah et al. (2023), who reported that children's creativity did not develop optimally in an early childhood institution where learning activities were dominated by imitation of teacher-provided examples. Children tended to struggle when asked to produce different outcomes, were less challenged by repetitive activities, and showed limited stimulation of curiosity. Such conditions restrict children's opportunities to construct understanding independently through observation, experimentation, and free exploration. Children should be supported in building their own understanding through these processes. Teachers can take on the role of facilitators, for example, by inviting children to observe various types and shapes of leaves in their environment and allowing them to choose which ones to use in their STEAM activities freely.

Providing children with autonomy not only supports the development of critical and creative thinking skills but also aligns with the principles of the *Merdeka Curriculum* for ECE, which emphasizes learning based on children's interests and experiences. This is reflected in the formulation of STEAM learning outcomes in ECE, which repeatedly use the term exploration ((Badan Standar, Kurikulum, Dan Asesmen Pendidikan kementerian Pendidikan, Kebudayaan, Riset, 2022). The repeated use of this term indicates that the *Merdeka Curriculum* positions exploration as a core learning process, requiring that children be given opportunities to observe, experiment, and discover independently, in line with their interests and learning experiences. Therefore, learning autonomy is essential to achieving the intended STEAM learning outcomes. Granting such freedom does not imply that teachers relinquish their role; rather, it points to more reflective and responsive facilitation tailored to children's learning needs. The learning outcomes for STEAM in ECE in the *Merdeka Curriculum* can be seen in the description below.

> *Children recognize and use pre-mathematical concepts to solve problems in everyday life. Children demonstrate basic critical, creative, and collaborative thinking skills. Children demonstrate curiosity through observation, exploration, and experimentation, using their surroundings and media as learning resources to gain insights into natural and social phenomena. Children demonstrate early abilities in using and engineering technology and seeking information, ideas, and skills safely and responsibly. Children explore various artistic processes, express themselves, and appreciate works of art.*

Teachers play a central role in creating meaningful learning experiences for children. Within the STEAM approach, teachers are not positioned as the sole source of knowledge, nor are children viewed as empty vessels to be filled. Instead, teachers are expected to stimulate children's curiosity and encourage them to ask questions, explore, observe, discover, and conduct inquiries independently. Therefore, teachers need to position themselves as learning partners rather than controllers or the center of the learning process. By working alongside children, teachers can create a safe yet challenging environment that allows children to experiment and construct their own understanding.

D. Conclusion

The implementation of STEAM learning in ECE is closely linked to teachers and school leaders' understanding. The findings show that the teacher at Kindergarten X tended to have a limited understanding of science, technology, and mathematics, which led to predominantly teacher-centered practices and restricted children's opportunities for exploration, critical thinking, and creativity. Although STEAM activities have been integrated using natural and contextual materials, the implementation has not yet fully reflected the child-centered and exploratory principles emphasized in the *Merdeka Curriculum*. The principal's broader understanding highlights the importance of instructional leadership in supporting teachers' pedagogical development. Therefore, strengthening teachers' conceptual and pedagogical understanding of STEAM is essential to ensure meaningful, developmentally appropriate learning experiences that foster curiosity, problem-solving skills, and holistic child development from an early age, as proposed in the learning outcome of STEAM in the ECE *Merdeka Curriculum.* Despite these insights, this study has limitations. It employed a qualitative case study design involving a single classroom teacher and a single school principal in a single ECE setting. The findings may only apply to this specific institution. Consequently, the results do not necessarily reflect the overall condition of ECE and STEAM implementation across Indonesia. To address this limitation, future research should optimize the scale of research by involving a larger and more diverse sample of schools, teachers, and school leaders.

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