The Importance of STEM Education in Early Childhood Education: Developing Critical Thinking at an Early Age

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ABSTRACT

There are still people who believe that the STEM approach is difficult to implement at the Early Childhood Education (ECE) level. They consider this approach more suitable for higher education levels. This is because students at this level possess the critical and advanced thinking skills required for STEM learning. Conversely, they argue that early childhood thinking abilities are still limited. They cannot think critically yet. Based on this reality, this research aims to prove that literacy, mathematics, science, technology, engineering, and arts education at the early childhood education level can foster children's critical thinking skills. Simple activities, such as playing with blocks in the Engineering Zone or exploring natural materials in the Natural Materials and Technology Exploration Zone, can stimulate and develop children's critical thinking skills. This research also aims to prove that learning in these zones, specifically the Engineering Zone and the Natural Materials and Technology Exploration Zone, constitutes STEM education. This research uses a qualitative descriptive research method. This research employs data collection techniques thru literature study and analysis of learning planning documents and implementation records in early childhood education (PAUD). This research finds that fostering critical thinking skills and STEM education is important at the PAUD level.

Keywords: Critical Thinking, STEM Education, Early Childhood Education.

INTRODUCTION

The advancement of technology and the rapid flow of information are hallmarks of modern life in the 21st century. These changes have a significant impact on contemporary life, including in the field of education. Education in the 21st century must also undergo changes. Learning that is solely focused on memorizing material is no longer suitable nowadays. On the contrary, teachers must encourage students to think critically, creatively, collaborate, communicate, and solve problems. Amidst technological advancements, the overwhelming flow of information, and social changes, all those competencies are very important. Therefore, STEM can be one of the appropriate learning approaches in the 21st century. The STEM approach integrates science, technology, engineering, and mathematics into meaningful learning experiences. Thru this learning, students can learn to think scientifically, use tools correctly, and conduct experiments and improvements on their ideas. Thru these learning experiences, students can construct their own knowledge.

Unfortunately, there are still people who think that STEM education is only suitable for higher education. They understand STEM as activities involving computer programming, laboratory experiments, or complex projects. With this understanding, they consider STEM learning to be less suitable for young children. Because their language skills are still simple. In addition, their way of thinking is still concrete. Thus, they are not yet able to think critically.

That view is certainly less accurate upon further examination. Early childhood children indeed cannot think critically in an abstract way like adults. However, they have a great sense of curiosity. They like to ask questions like "what," "why," and "how." This proves that they actually have a foundation for critical thinking. In addition, they can also distinguish and compare objects around them. They also enjoy conducting simple experiments. Karademir and Yıldırım (2021) state that young children essentially have a natural curiosity and can be considered "young scientists." Because they actively observe, enjoy asking questions, can make cause-and-effect connections, and try to understand the world around them. Therefore, STEM learning in early childhood education (ECE) should be conducted thru various activities that provide space for children to explore, investigate, build, and think.

In the context of early childhood education (PAUD), STEM learning cannot be separated from the principle of learning thru play. The Ministry of Education, Culture, Research, and Technology (2022) thru the book Building the Foundation of STEAM Thru Play Activities emphasizes that early childhood has the potential to develop the foundations of scientific, technological, engineering, artistic, and mathematical thinking if they receive appropriate stimulation thru play activities. Therefore, teachers need to facilitate high-quality play activities, making them meaningful and challenging.

STEM learning in early childhood education can also build critical thinking skills from an early age. Early childhood children indeed cannot think critically like adults. They are not yet able to evaluate abstract opinions. They also cannot analyze complex concepts yet. Critical thinking in early childhood is evident thru concrete behavior. They observe problems and provide simple solutions. They can find cause-and-effect relationships. They are also brave enough to ask questions or express their opinions simply. Ningsih et al. (2022) showed that the scientific approach with activities such as observing, questioning, gathering information, associating, and communicating can develop critical, logical, and creative thinking skills in early childhood. Lay et al. (2026) also found that scientific learning positively affects the critical thinking abilities of children aged 4–5 years. These findings further strengthen this research that young children have the potential for critical thinking. This can happen if teachers provide an exploratory and dialogic learning environment.

Previous studies have also found a relationship between STEM/STEAM education and the critical thinking skills of early childhood children. Azizah et al. (2022) showed that the critical thinking skills of children aged 5-6 years can grow thru exploratory STEAM-based learning. Sukmawati and Rakhmawati (2023) also show that STEAM learning can develop higher-order thinking skills, including critical thinking and problem solving, in early childhood. Muawanah and Harjani (2024) proved that there is an improvement in the critical thinking skills of 4-5 year old children thru STEAM learning with loose parts media. In line with that, Prameswari and Lestariningrum (2020) also found that loose parts-based STEAM learning can support 4C skills. This has a significant impact on children's critical thinking.

METHOD

This research uses a qualitative descriptive approach. This is because the research aims to describe, explain, analyze, and interpret the implementation of STEM learning in zones, specifically the Engineering Zone and the Natural Materials and Technology Exploration Zone. In addition, this research also demonstrates the impact of STEM learning on the critical thinking abilities of early childhood children in a natural way.

The data sources for the research are literature studies and qualitative field studies on learning planning documents and implementation records in early childhood education (PAUD). In the literature study, the research uses books, guides, and journal articles on STEM/STEAM learning, scientific learning, critical thinking in early childhood, science learning, loose parts, center or zone learning, and the role of teachers in developing critical thinking skills. Thru this literature study, the research builds a conceptual foundation on STEM learning in zones and critical thinking skills in early childhood.

Next, the research conducted a content analysis of the learning planning. The focus of the analysis is the mapping of essential components of science, technology, engineering, and mathematics with the Learning Objectives of children's play activities. This research also utilizes learning implementation records in the zones, specifically the Engineering Zone and Natural Materials and Technology Exploration Zone. The notes on the implementation of learning are related to activities such as sound exploration, the use of magnifying glasses, guessing aromas, making oobleck, creating disability aids from loose parts, and building ramps or aids with blocks. From the notes, the teacher acts as a facilitator and the children as active subjects during the play activities.

The subjects in this study are the lesson planning documents for Kindergarten B and the implementation records of the lessons for the

Kindergarten B group (ages 5-6 years). This research focuses on children's play activities that are contextual with the theme "God Created Me Great" and the sub-theme about "People with Disabilities." The data analysis technique in this study uses the interactive model of Miles and Huberman (Ningsih et al., 2022), which consists of three simultaneous activity flows. First, data reduction is carried out by selecting and simplifying raw data into STEM indicators and critical thinking. Then, the data is presented in the form of descriptive narratives, comparisons, and conversation quotes. Next, draw conclusions and provide evidence based on the presented data.

FINDINGS AND DISCUSSION

1. Characteristics and Indicators of STEM Learning at the Early Childhood Education Level

Childhood Education Level The implementation of STEM learning at the Early Childhood Education (ECE) level has operational characteristics that significantly distinguish it from both the primary and secondary education levels. STEM in early childhood education (ECE) is not a separate subject taught in a rigid theoretical or academic manner, but rather an approach that is holistically integrated into various meaningful inquiry-based play activities (Ministry of Basic and Secondary Education, 2025).

Early childhood children learn thru hands-on experience, manipulation of concrete objects, and active social interaction. Huda et al. (2024) state that this approach is essential for building interdisciplinary understanding, creativity, problem-solving skills, and a foundation for critical thinking from an early age.

Therefore, STEM learning in early childhood education should be kept away from abstract technical terms. Children are not directed to memorize concept definitions, but rather to directly experience simple science and engineering processes. In more detail, the mapping of the operational indicator matrix along with examples of concrete activities in the field is presented in the following Table 1 (Ministry of Education, Culture, Research, and Technology, 2022):

Table 1:
Operational Indicators and Concrete Examples

STEM components	Operational Indicators in Early Childhood Education	Example of Concrete Activity
Science	Involving sensory observation, recognition of physical characteristics of objects, exploration of natural materials, testing simple predictions, and understanding causality.	Observing leaf veins, guessing the aroma of natural ingredients, observing changes in dough texture.

Technology	The use and introduction of non-digital physical aids made by humans to facilitate simple scientific investigations.	Using a magnifying glass (loupe), dropper, funnel, measuring container, and sound catcher.
Engineering	Construction activities that involve the design thinking process, such as designing, building, testing stability, and modifying the structure of objects.	Arranging blocks so they don't fall, assembling a ramp, creating a prototype of a physical aid.
Mathematics	The application of basic pre-mathematics concepts, such as the introduction of geometric shapes, spatial relationships (position and direction), comparative measurement, patterns, and object classification.	The application of basic pre-mathematics concepts, such as the introduction of geometric shapes, spatial relationships (position and direction), comparative measurement, patterns, and object classification.

The quality of the thinking process is what distinguishes STEM learning from regular play activities. For example, the activity of stacking blocks will only be a regular gross motor exercise if the child simply piles them up without purpose. However, the activity transforms into STEM learning when the teacher provides a problem context, challenges the child to design a structure, encourages them to observe balance, and asks for an explanation of their choice of block shapes.

The stimulation of an open, creative, and collaborative learning environment by teachers has proven effective in supporting children's 21st-century skills (Prameswari & Lestariningrum, 2020). In addition, STEM learning media in early childhood education (PAUD) is not limited to loose parts materials, but can also optimize the use of household items and natural materials around the child, such as water, flour, string, and cups.

2. Critical Thinking Skills in Early Childhood

The myth that young children are not capable of critical thinking has been debunked by various empirical facts in the field. The ability to think critically in the foundational phase is not measured thru written tests or abstract evaluations, but rather identified thru concrete behavioral indicators in daily activities when children engage in exploratory activities, material manipulation, or idea expression.

Based on the literature review, there are four main behavioral indicators of critical thinking in early childhood (Lestari & Wati, 2026):

a. Ability to Ask Questions (Inquiry) Children show deep curiosity thru the formulation of active causal questions, such as "Why is that?" or "Where does the sound come from?".
b. Problem-Solving Ability Children are able to independently find alternative solutions when encountering obstacles or failures during play activities.
c. Understanding Cause-and-Effect Relationships (Causal Reasoning) Children are able to correlate their physical actions with the impacts or changes in phenomena that arise.
d. Articulation of Ideas Children are able to explain the purpose of their construction design, present the results of their simple investigations, and reflect on their learning experiences.

The above indicators are directly related to the ability to observe in depth, compare variations in stimuli (loud-soft sounds, smooth-rough textures), group objects, and predict changes in the results of actions (for example, estimating the addition of flour to address overly runny dough). Vitriyana et al. (2025) state that the main trigger for the emergence of critical thinking skills is project-based learning with a focus on science and technology content, where children are given full space to experiment, observe changes, and make independent decisions.

3. Integration of STEM in Zone-Based Learning Planning

Based on the analysis of the zone regulation guide documents and Teaching Modules (Lesson Plans), the STEM approach in Early Childhood Education (PAUD) is systematically integrated thru a zone-based learning model. This integration is contextually applied in Semester 1 with the major theme "God Created Me Great" and the subtheme "Persons with Disabilities." This curriculum maps the Learning Objectives Pathway (ATP) that directly supports the STEM components in two specific areas: The Engineering Zone and The Natural Materials and Technology Exploration Zone.

a. Learning Design Plan in the Engineering Zone In the Engineering Zone, the document sets Learning Outcomes so that children can recognize and use pre-mathematical concepts to solve everyday problems. The teacher's task is to arrange the physical environment (the learning environment as the "third teacher") by providing a variety of construction materials separately based on their type and shape on open shelves. The materials include natural wooden blocks, plastic blocks, foam blocks, magnetic components, and loose parts.
b. This structured arrangement aims to spark children's interest in design engineering activities, such as building, assembling, disassembling, and designing prototypes of mobility aids for people with disabilities. The internal curriculum document defines this zone as a constructive play area that simultaneously supports the understanding of concepts such as geometry, space, balance, size, patterns, and group cooperation (BPK

PENABUR Jakarta, 2025). This shows a strong alignment with the engineering and mathematics components in STEM.

c. Learning Design Plan in the Natural Materials and Technology Exploration Zone In the Natural Materials and Technology Exploration Zone, the learning objectives are directed so that students demonstrate scientific curiosity thru observation, exploration, experimentation, and the use of simple non-digital technology functions. The teacher is responsible for providing simple laboratory equipment that is safe for children, such as magnifying glasses, tweezers, measuring containers, plastic funnels, dropper pipettes, mattress threads, and paper cups. Thru these operational media, children are facilitated to conduct independent investigations into the functions of the human senses and the physical mechanisms of sound wave propagation.

4. Implementation of STEM and Critical Thinking Stimulation in the Natural Materials and Technology Exploration Zone

In this zone, children are challenged to conduct simple physics science experiments to explore the human sense of hearing thru the mechanism of sound propagation in solid media. The experiment was conducted using a homemade mechanical technology tool in the form of an iron spoon tied with a mattress/wool string and connected to a plastic cup (String Telephone or Fork on a String). The integration of STEM components in this activity is described as follows:

a. Science: Observing the source of sound, the vibration of the spoon, and the phenomenon of sound wave propagation.
b. Technology: Combining the spoon, string, and cup into a single mechanical sound-capturing system.
c. Engineering: Assembling the tool components and testing them to ensure optimal functionality.
d. Mathematics: Measuring the length of the string and comparing sound intensity (loud, soft, high, low).

Empirical evidence of the child's high-level scientific reasoning ability is clearly recorded in the following excerpt of the verbatim dialog transcript:

Teacher: "Where does the sound come from?"
Child 1 : "From the spoon, Ms."
Child 2 : "The spoon is shaken until it hits the table, and it makes a sound."
Teacher: "What kind of sound?"
Child 3 : "It sounds like ting ting."
Child 4 : "It sounds like tok tok."
Child 5 : "There's no sound, Ms..." (Child looks confused because the tool is not working)

Teacher: "How did you do it earlier?" (Teacher gives a prompting question, not directly dictating the answer)
Child 5 : (Re-examines the tool, observes the position of their own hands) " Eh, when I shook it, I held the string here, Ms..."
Teacher: (Gives another example without holding the string, letting the child try again)
Child 5 : (Tries again by letting go of the string; the spoon hits the table and the sound is heard clearly in the glass) " Wow, there's a sound, Ms! Loud!"
Child 3 : (Observing the process closely and then asking) "Ms, why can the sound be heard thru the string?"
Teacher: "The sound from the spoon travels thru the string, which is why it can be clearly heard from the cup to your ear."

Based on the analysis of the interaction above, the main indicators of the child's critical thinking that emerged clearly are:

a. Problem Solving and Cause-and-Effect Reasoning: Explicitly demonstrated by Child 5. When his experiment failed, the child did not act passively. Encouraged by the teacher's prompting question, he conducted a reflective analysis of his actions. The child successfully identified that holding the rope was the 'cause' of the dampened vibration, and the 'solution' to the problem was to release the grip so that the sound waves could propagate freely ('effect').
b. High-Level Questioning Ability: Demonstrated by Child 3 thru a conceptual causality question ("Why can the sound be heard thru the string?"). This question proves that the child is not merely engaging in physical play, but is cognitively driven to understand the scientific mechanisms behind the observed phenomenon.

This stimulation is reinforced during outdoor learning sessions. The children used a technological tool in the form of a magnifying glass (loupe) to observe the structure of dry leaf veins, the movement of ant colonies, and the texture of rocks in the schoolyard. This activity triggers the emergence of the indicator of Articulation of Ideas descriptively: "The ants look big, Ms, they have so many legs!" This leaf has stripes like a highway..."

This field fact aligns with the findings of Lestari and Wati (2026) in the Murhum Journal that exploration of the natural environment supported by scientific tools is very effective in stimulating children's logical reasoning thru the optimization of the five senses. Activities in this zone prove that thru concrete media, a solid foundation for children's critical thinking can be built.

5. Implementation of STEM Learning in the Engineering Zone

In the Engineering Zone, children are challenged to solve social-contextual problems derived from the weekly subtheme: designing and building prototypes of disability-friendly facilities. As a visual stimulus, the teacher provides real picture cards of blind glasses, wheelchairs, guide canes, and ramps. The integration of STEM components is realized transdisciplinarily:

a. Science & Technology: Recognizing the mechanical functions and uses of disability aids in real life.
b. Engineering: Physically constructing beams, assembling, and maintaining the stability of structures to prevent collapse.
c. Art: Actualizing visual creativity in designing the beauty of houses and disability-friendly facilities.
d. Mathematics: Conducting spatial reasoning and identifying the geometric shapes of beams that precisely meet the building's requirements.

The following dialogic interaction shows how the child's higher-order thinking skills (HOTS) are stimulated in this zone:

Child : "I made a house, Ms!"
Teacher: "Whose house is this?"
Child : "My friend's house."
Teacher: "Earlier, I asked us to make a disability aid. What kind of aid does your friend's house have?"
Child : "Not yet, Ms. I'll give it later."
Teacher: "Which one will you make for that house?" (While pointing to the board with pictures of disability aids)
Child : (Carefully observing the picture board and then pointing to one) " This Ms, I want to make this one..." (Child points to the picture of a ramp/wheelchair slope)
Teacher: "Oh, to make a slope like that, which block shape will you use?"
Child : (Looks at the block shelf, comparing the shapes of cube, cylinder, and triangle) " Use the triangular one, Ms, so the block can be slanted.
Teacher: "Sure, go ahead and try."

From the recording of the interaction above, two main indicators of critical thinking ability are evident:

a. Articulation of Ideas: When the teacher provides scaffolding in the form of reflective prompt questions regarding the building's alignment with the theme, the child does not experience cognitive obstacles. The child was able to communicate their engineering idea very clearly after observing the image stimulus.
b. Understanding Cause-and-Effect Relationships (Causal Reasoning): The child successfully connected the geometric characteristics in the picture with the block materials in the classroom. The child's decision to choose triangular prism blocks demonstrates critical causal reasoning: he

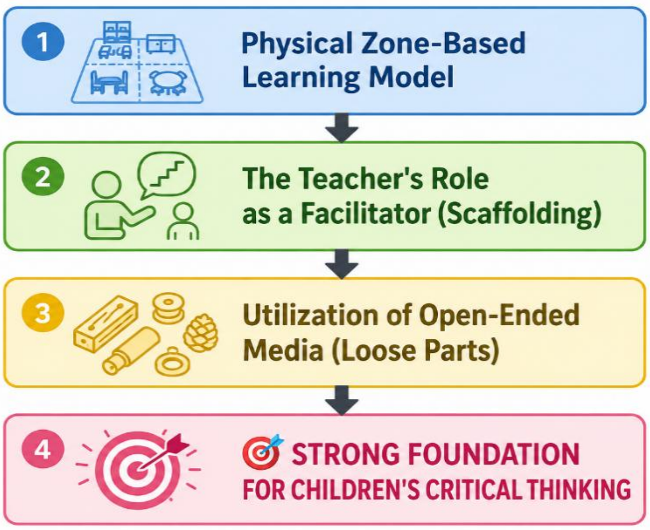
understands that the 'cause' of using triangular blocks will result in the 'effect' of a functional ramp structure that can be traversed by a toy wheelchair.

This empirical finding simultaneously reinforces the theory of Ningsih et al. (2022) in JECIE, which states that a contextual scientific approach thru constructive-manipulative play activities is very effective in training children's critical, logical, and spatial thinking skills from an early age without exploiting their developmental phase.

6. Potential, Relevance, and Success Factors of STEM at the Early Childhood Education Level

All the findings in this study clearly debunk public skepticism that considers the STEM approach too abstract and only suitable for higher education levels. The results of document analysis and field implementation records show that the realm of Early Childhood Education (ECE) has extraordinary potential in naturally integrating STEM content thru the principle of learning thru play. When the learning environment is arranged thru inquiry, children have been proven capable of conducting complex scientific cycles: observing phenomena, conducting experiments, asking critical questions, experiencing design failures, and making independent improvements. Comprehensively, the success of STEM implementation at the early childhood education level in this study is influenced by three interrelated main factors:

Picture 1:
Synthesis of the Pathway to Success Factors for STEM Implementation in Early Childhood Education



a. Physical Zone-Based Learning Model: The arrangement of the classroom into specific zones (Engineering Zone and Natural Materials and Technology Exploration Zone) has successfully shifted the learning paradigm to be child-centered. This zone provides psychological and physical space for children to explore their curiosity without the rigid barriers of academic doctrine.
b. The Role of the Teacher as a Facilitator and Catalyst: The teacher no longer acts as the sole instructor dictating answers, but rather as an environment designer and provider of scaffolding. Thru inquiry communication techniques and the provision of reflective prompting questions (such as "How did you do it earlier?"), the teacher successfully guides the child to discover scientific concepts and solutions on their own.
c. Utilization of Open Media (Loose Parts and Blocks): The availability of learning media that is open, multifunctional, and manipulative provides full independence for children to construct their own knowledge. It is this concrete media that bridges the child's mind (which is still in the pre-operational phase) to understand STEM concepts that are often considered abstract by adults.

The habituation of STEM-based activities integrated into early childhood education (PAUD) shapes children's thinking habits (habits of mind) to become critical, analytical, and solution-oriented individuals from an early age, which is an important asset for the future. This is in line with the findings of Umma et al. (2025), which show that science learning based on direct experiments significantly enhances children's critical thinking skills thru observation, reasoning, problem-solving, and communication.

The STEM approach in this research expands those findings. The transdisciplinary integration of science, technology, engineering, art, and mathematics makes all indicators of children's critical thinking not emerge separately, but rather stand out in an integrated and simultaneous manner thru a single enjoyable play activity.

CONCLUSION

This qualitative descriptive research proves that the STEM approach is not only relevant for higher education levels but can also be effectively, contextually, and meaningfully implemented at the early childhood education level. Thru the optimization of zoned spatial arrangements, particularly the Engineering Zone and the Natural Materials and Technology Exploration Zone, young children have been shown to develop critical thinking skills from an early age.

Analysis of planning documents and implementation records shows that simple inquiry play activities, such as experimenting with sound propagation or designing wheelchair paths using blocks, can stimulate key indicators of critical thinking in the foundational phase. Children have been shown to be capable of asking investigative questions, analyzing cause-and-effect relationships, solving problems independently when experiencing design failures, and communicating their spatial ideas. This confirms that STEM education in early childhood can lay a solid foundation for reasoning without burdening children with abstract academic targets.

However, this research still has limitations because the observation focus is currently limited to two specific learning zones. Therefore, it is recommended for future researchers and education practitioners to expand the research locus to other play zones, such as the Role Play Zone, Art Zone, or Literacy Zone. This expansion is important for formulating a more comprehensive, integrative, and holistic STEM implementation model in the future.

ACKNOWLEDGEMENT

The author thanks to the teachers, technicians, and students for their great cooperation and support during the activities in the learning zones.

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