STEM Learning through the Engineering Design Process for Early Childhood Critical Thinking in Islamic Kindergarten

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Abstract
Early childhood education (ECE) plays a pivotal role in shaping the fundamental attitudes and developmental milestones of children, serving as the cornerstone for human resource development. Optimal stimulation in ECE is a result of the synergy between family environments and formal education, where teachers act as primary facilitators in delivering integrated services encompassing education, health, and critical thinking. This study explores the relevance of the Science, Technology, Engineering, and Mathematics (STEM) approach, which emphasizes scientific reasoning, collaboration, and creativity through playful exploration. Specifically, this research focuses on TK Islam Miftahul Fath Bandung, an institution that integrates Islamic curricular values—balancing spiritual and cognitive development. Despite its holistic vision, current pedagogical practices remain predominantly focused on repetitive rote learning, such as memorizing prayers and reading Iqra. To address this, the school has recently socialized a project-based learning system for educators. This study aims to analyze the integration of the Engineering Design Process (EDP) as a structured framework within project-based learning to achieve more robust learning objectives. By shifting from repetitive activities to systematic problem-solving through EDP, teachers are expected to provide more dynamic and meaningful stimulation, ensuring that students are better prepared for their future social and academic environments.
Keywords: Early Childhood Education, STEM, Engineering Design Process (EDP), Project-Based Learning, Islamic Education.

INTRODUCTION

The landscape of early childhood education has undergone a significant paradigm shift, evolving from merely providing basic care to serving as a foundational pillar for developing complex cognitive architecture, character, and lifelong learning dispositions. During the critical early years, children experience unparalleled neuroplasticity and growth across cognitive, affective, and psychomotor domains. Consequently, pedagogical strategies implemented in early childhood education institutions bear a profound responsibility to stimulate holistic development, particularly in cultivating critical thinking skills (Priyanti & Warmansyah, 2021). Critical thinking in early childhood is not merely an academic requirement but a vital survival competency, enabling children to observe phenomena, hypothesize causal relationships, and make evidence-based decisions (Fisher, 2011). However, a persistent global challenge remains the dominance of teacher-centered learning models, where children are

positioned as passive recipients engaged in rote memorization and imitation, thereby stifling their innate curiosity and limiting the optimal development of critical thinking (Yulia & Sarifah, 2025).

In the Indonesian context, although significant progress has been made in early childhood education policies and curriculum development, societal awareness regarding the depth of early childhood education's role in unlocking human potential remains fragmented. The government has sought to strengthen systemic competencies through standardized training programs for educators, aiming to align teaching practices with rapid technological advancements. Nevertheless, the quantitative availability of high-quality early childhood education institutions remains insufficient to meet national demand. Existing interventions, such as the Bina Keluarga Balita program, often lack the pedagogical integration required to provide comprehensive intellectual stimulation. This service gap results in children entering primary education without a robust foundation in critical thinking, which is essential for navigating the complexities of the twenty-first century. High-quality early childhood education must be viewed through a multidimensional lens, encompassing scientific, moral, social, and economic benefits to enhance the nation's future quality of life.

A holistic perspective on early childhood education emphasizes the interconnection of education, health, and psychological well-being. Within the framework of Islamic pedagogy, each child is born in a state of fitrah, representing a latent potential for spiritual, intellectual, and social balance (Parinduri, 2022). Islamic scholars, such as Al-Ghazali, regard children as sacred trusts requiring harmonious education that nurtures the intellect, heart (qalb), and body in accordance with divine principles (Sarkowi, 2018). This aligns with contemporary developmental theories by Piaget and Vygotsky while introducing a spiritual dimension, wherein cognitive processes are perceived as tazkiyatun nafs or the purification of the soul through exploration of ayat kauniyyah, the signs of God in nature (Arifin, 2016). Accordingly, early childhood education within Islamic environments aims not only for cognitive excellence but also for fostering dual identities as abdullah and khalifatullah, integrating ethical comportment with intellectual sharpness (Gumiandari, 2021).

To bridge the gap between traditional rote learning and contemporary competency requirements, the integration of Science, Technology, Engineering, and Mathematics (STEM) has emerged as a globally recognized integrative model. STEM education encourages hands-on exploration, enabling children to engage directly with their environment through observation, questioning, and experimentation (Bybee, 2013). Within STEM, the Engineering Design Process (EDP) provides a structured yet iterative framework for problem-solving. EDP

shifts the focus from merely finding the correct answer toward an open-ended process of questioning, imagining, planning, creating, and testing (Lyn, 2016). This model fosters resilience by teaching children to perceive failure as data for improvement, thereby enhancing problem-solving capabilities through real-world applications (Tipmontiane & Williams, 2022). When EDP is successfully embedded in the curriculum, children transition from passive consumers of information to active designers of solutions (Siddika Selcen Guzey et al., 2016).

However, significant tensions arise at the grassroots level, particularly in institutions such as TK Islam Miftahul Fath Bandung. While the school aspires to balance spiritual values with cognitive development, current practices are often anchored in repetitive spiritual routines, such as memorizing prayers and reading Iqra, leaving limited space for scientific inquiry. Educators face the formidable challenge of integrating modern approaches, including STEM and EDP, without compromising Islamic values (Judijanto & Yusniar, 2025). Although project-based learning and EDP frameworks have recently been introduced, their actual implementation remains challenging for teachers accustomed to traditional methodologies. This situation reflects a broader academic gap in which the theoretical benefits of STEM-EDP are well-documented, yet practical integration into faith-based early childhood curricula and its subsequent impact on critical thinking remains underexplored.

This study seeks to address this critical intersection. By examining the implementation of STEM through the Engineering Design Process (EDP) at TK Islam Miftahul Fath Bandung, the research aims to describe pedagogical shifts occurring within the classroom. Additionally, the study analyzes teacher strategies for fostering critical thinking and identifies systemic facilitators and barriers inherent in this integration. The significance of this study lies in its potential to offer an innovative synthesis, in which scientific exploration and spiritual contemplation (tadabbur) coexist to produce a generation of children who are not only technologically literate but also spiritually grounded and capable of critical thinking (Kholis Nur, 2025). Through this exploration, the research aspires to provide a roadmap for early childhood education institutions to evolve their curricula toward more holistic, future-oriented, and faith-aligned learning experiences.

RESEARCH METHODS

This study employed a qualitative method with a descriptive design to explore the dynamics of learning in depth through direct interaction with subjects in their natural environment. The choice of a qualitative approach was motivated by the need to gain a comprehensive understanding of pedagogical phenomena, while the descriptive approach was used to elaborate on how the implementation of STEM influences the development of critical thinking skills in early childhood (Wiwin Yuliani, 2017). This strategy enabled the researcher

to capture the complex realities underlying instructional practices that cannot be measured solely through statistical methods. The study was conducted at TK Islam Miftahul Fath Bandung, an institution that integrates religious values with modern curriculum innovation. The research took place during the odd semester of the 2025/2026 academic year, specifically from September to November 2025. The research activities included participatory observation, in-depth interviews, and document analysis, focusing on learning activities in Class B.

Informants were selected using purposive sampling, deliberately chosen based on their capacity to provide the most relevant information regarding learning practices in the school (Wiwin Yuliani, 2017). The primary subjects were the Class B teacher, who served as the designer and implementer of STEM-based learning. To enhance data validity and achieve triangulation, the principal and students' parents were involved as supporting informants. Research data were categorized into primary data, obtained directly from interactions with teachers and students in the classroom, and secondary data, which included Daily Lesson Plans (RPPH), activity schedules, photographic documentation, and profiles of the Islam-based curriculum.

Data collection was conducted using three main instruments: observation, interviews, and documentation. Non-intervention participatory observation was carried out over three weeks to monitor the Engineering Design Process (EDP)-based learning without disrupting classroom instruction (Spradley & Huberman, 2024). The researcher focused on observing how the teacher designed activities, children's exploratory responses, and indications of emerging critical thinking skills, such as asking questions and making simple decisions. In addition, open-ended interviews were conducted with the teacher and principal to explore perceptions, strategies, and systemic obstacles in STEM integration. All data were supported by documentation, including activity videos and teacher planning archives, serving as empirical evidence to verify verbal interpretations.

Data analysis was conducted interactively and continuously from data collection to conclusion drawing, following a systematic analysis model (Spradley & Huberman, 2024). The process began with data processing, including verbatim transcription of interviews and organization of field notes according to the chronology of activities (Bingham, 2023). The researcher then performed data reduction by eliminating irrelevant information and applying coding techniques to classify data into thematic categories, such as teacher strategies, children's responses, and implementation barriers. Categorized data were subsequently presented in matrices or descriptive narratives to clearly map relationships among themes. The final stage of analysis involved drawing conclusions and verification, in which the researcher interpreted the meaning of

observed patterns to answer research questions regarding the effectiveness of the EDP model in stimulating critical thinking and identifying supporting and inhibiting factors in the field.

To ensure the validity and credibility of findings, this study applied four main criteria aligned with qualitative research quality standards (Bingham, 2023). First, source triangulation was conducted by comparing perspectives from different informants, along with method triangulation through cross-checking observation, interview, and document data. Second, member checking was implemented by confirming the interpretations with informants to ensure alignment with their lived experiences. Third, observational diligence was maintained through repeated monitoring of various learning activities to ensure data consistency. Finally, an audit trail was applied, documenting the entire research process from raw notes to the final report as a form of academic accountability.

RESULT AND DISCUSSION

The findings of this study illustrate that TK Islam Miftahul Fath provides a rich, holistic early childhood education environment that integrates Islamic values, cognitive development, and socio-emotional learning, aligning with contemporary theories on child-centered pedagogy (Piaget, 1972; Vygotsky, 1978). The institution's strategic location within a densely populated and culturally diverse community enables children to engage in learning experiences that are both contextually relevant and socially meaningful. The school's longstanding presence since 1997, combined with its affiliation to Yayasan Baiturrahman Indonesia, has established a framework for sustained educational practices that cater to children aged 4–6 years, emphasizing both foundational skills and moral development (Priyanti & Warmansyah, 2021).

The demographic characteristics of students reveal a heterogeneous population in terms of socio-economic background and home support, which directly influences readiness in cognitive, motor, and socio-emotional domains. Consistent with the ecological systems theory (Bronfenbrenner, 1979), the findings suggest that child development at TK Islam Miftahul Fath is shaped not only by formal instruction but also by home and community contexts. The variability in parental involvement, largely due to occupational commitments, underscores the necessity for structured school-family partnerships. Initiatives such as parenting classes, storytelling activities, and literacy programs demonstrate proactive strategies to bridge gaps between home and school, reflecting an understanding that learning outcomes improve when children receive coherent stimulation across settings (Epstein, 2011).

Curricular practices at TK Islam Miftahul Fath emphasize active learning through play, exploration, and project-based approaches, which stimulate the

six foundational domains of early childhood development: religious and moral values, physical-motor skills, cognitive abilities, language, social-emotional competence, and arts (Fisher, 2011; Bybee, 2013). The integration of Islamic spiritual practices with STEM-inspired experiential learning aligns with the holistic-integrative early childhood education model, where cognitive, moral, and creative development occur simultaneously (Arifin, 2016; Gumiandari, 2021). Children are encouraged to engage in meaningful activities that promote inquiry, problem-solving, and self-expression, fostering intrinsic motivation and early critical thinking. This pedagogical approach resonates with research emphasizing that active engagement and autonomy in early learning contexts are crucial for fostering lifelong learning attitudes (Lyn, 2016).

The study also highlights areas for improvement, particularly in basic literacy and active thinking skills. While children are exposed to early numeracy and literacy through classroom corners and reading activities, access to reading materials at home is limited due to socio-economic factors. As suggested by Vygotsky (1978) and contemporary literacy research, scaffolding literacy within the school environment, complemented by culturally relevant content such as Sundanese folktales and regional songs, can mitigate environmental disparities and enrich the learning experience (Siddika Selcen Guzey et al., 2016). Moreover, encouraging children to ask questions, explore, and solve simple problems can enhance cognitive and creative development, underscoring the importance of teacher facilitation that balances guidance with child-led discovery (Tipmontiane & Williams, 2022).

Teachers and educational staff demonstrate high professional commitment, combining academic qualifications in early childhood education with strong religious knowledge, thereby embodying the school's vision of producing "pious, intelligent, and confident children." Their active participation in professional development programs, including training in the Merdeka Curriculum and Project-Based Learning, reflects ongoing efforts to align teaching practices with best-practice pedagogical frameworks (Spradley & Huberman, 2024). Despite these strengths, the analysis indicates that further enhancement is required in teacher strategies for stimulating active thinking and fostering early literacy, which remain critical for holistic development (Bingham, 2023).

Parent-school partnerships emerge as a pivotal factor in optimizing early childhood outcomes. The study reveals that while parental enthusiasm exists, active engagement is inconsistent due to time constraints and limited understanding of pedagogical needs. Consistent with Epstein's (2011) model, effective partnerships should involve inclusive, context-sensitive strategies such as storytelling sessions, parent workshops, digital library access, and structured communication channels. Strengthening these partnerships can provide

children with continuity of learning, reinforce socio-emotional support, and cultivate a collaborative culture that extends beyond the classroom (Yulia & Sarifah, 2025).

Finally, the findings underscore that TK Islam Miftahul Fath successfully implements a curriculum that integrates academic and non-academic domains, stimulating cognitive, social, emotional, and creative capacities in a balanced manner. By combining structured pedagogical practices with play-based exploration, culturally relevant literacy, and parental involvement, the school fosters children's active participation, curiosity, and early critical thinking. Such an approach reflects a sophisticated understanding of early childhood education that is both culturally grounded and forward-looking, preparing students to navigate complex social and intellectual challenges in the twenty-first century (Priyanti & Warmansyah, 2021; Bybee, 2013).

Planning for STEM Learning at TK Islam Miftahul Fath
Learning planning at TK Islam Miftahul Fath is designed as a strategic guide to assist the institution in formulating structured and measurable learning goal paths. The Learning Outcomes in this curriculum are integrated into three main stimulation elements which include Religious and Moral Values, Self-Identity, and the Foundations of Literacy, Mathematics, Science, Technology, Engineering, and Arts. These three elements were developed to respond to the needs of twenty first century education in Indonesia while remaining rooted in the strengthening of the six basic foundations of Early Childhood Education (ECE). The implementation of this planning also aligns with regulatory mandates regarding the prevention of violence in educational units as well as the Healthy School Program which emphasizes the mental health and emotional maturity of students.

Execution of STEM Learning
The execution of learning at this institution focuses on the internalization of eight dimensions of the graduate profile which include faith, citizenship, critical reasoning, creativity, collaboration, independence, health, and communication. The dimensions of critical reasoning and creativity serve as the core of STEM integration where children are directed to think logically and innovatively in solving simple problems. The instructional process is carried out based on the principles of conscious, meaningful, and joyful learning. The principle of meaningfulness is implemented by linking teaching materials to real situations in the surrounding environment so that children can understand the relevance of science in daily life.

The pedagogical strategy used by teachers involves the utilization of concrete media and real learning resources to simultaneously stimulate the aspects of intellectual, ethical, aesthetic, and kinesthetic development. Within the

Foundations of Literacy and STEM elements, children are encouraged to develop sensitivity to numbers, recognize patterns, and understand cause and effect relationships through simple scientific exploration. The intracurricular programs and learning projects for the 2025/2026 academic year are organized thematically ranging from the topic of self identity to natural phenomena such as the process of rainbows and volcanic eruptions. This approach ensures that every activity is not only academic but also capable of building the character of abdullah who possesses a sense of awe toward the creations of God.

Evaluation of STEM Learning

Evaluation of STEM implementation indicates that this approach is highly relevant to the exploratory learning characteristics of early childhood. Although receiving positive responses from parents and high enthusiasm from students, teachers face complex challenges in its execution. Limitations in time and institutional resources constitute the main barriers to designing in depth STEM projects. Furthermore, there is a gap in teacher confidence regarding the mastery of engineering and technology materials due to varied academic backgrounds.

The transition from a teacher centered learning model to a student centered model requires consistent pedagogical adaptation. Teachers are required to manage a flexible learning environment without neglecting the safety and comfort of the child. To overcome these constraints, adequate policy support and continuous training through learning communities are necessary so that educators can constantly update their skills in accordance with the advancement of digital technology and artificial intelligence. Effective STEM integration ultimately depends on the ability of teachers to harmoniously balance cognitive achievement with psychosocial development needs.

Evaluation and Assessment Dynamics in STEM-Based ECE

The implementation of assessment in STEM projects at TK Islam Miftahul Fath demonstrates a fundamental shift from end result evaluation toward the monitoring of thought processes that are formative and authentic. Teachers act as keen observers who document child engagement through anecdotal notes and checklists aligned with science development indicators. This approach ensures that assessment is no longer trapped in the dichotomy of right or wrong but focuses on how children propose ideas, attempt solutions, and explain their work (Bingham, 2023). The integration of assessment into every stage of the Engineering Design Process (EDP) provides comprehensive data regarding the individual strengths of the child and specific intervention needs without disrupting their comfort while playing. The success of this assessment model proves that evaluation integrated with exploratory activities is capable of providing a more accurate picture of the cognitive and socio emotional progress of early childhood (Spradley & Huberman, 2024).

The Synergy of Engineering Design Process (EDP) and Daily Learning
daily learning structures that integrate spiritual routines with core activities based on EDP create a unique balance between religious values and scientific proficiency. Through the alternative lighting project, children are invited to transcend the boundaries of their imagination by facing real problems such as power outages at night. The Ask and Imagine stages trigger deep curiosity through prompting questions about the origin of electricity and the properties of flammable objects, which are then manifested into concrete plans at the Plan stage. Children demonstrate extraordinary ability in understanding technical instructions when assembling prototypes using simple materials such as cooking oil, pebbles, and cotton buds. This process fosters independence and intellectual sharpness aligned with the concept of 'aql in the Islamic perspective where learning is a form of contemplation of natural phenomena (Arifin, 2016).

Cultivating Critical Thinking through Effective Questioning
One of the key findings in this study is the vital role of effective questioning techniques performed by teachers as a pedagogical bridge in mediating STEM abstractions for early childhood. Since children in the foundation phase are not yet fully capable of abstract thinking independently, open ended questions posed by the teacher become catalysts for the development of higher order thinking. Teachers at TK Islam Miftahul Fath utilize exploratory questions to encourage children to define problems, choose appropriate materials, and perform self evaluation at the Improve stage. Through this meaningful dialogue, children do not merely follow technical instructions but learn to perform cause and effect analysis, such as understanding why their alternative lighting device might not ignite. This strategy effectively transforms the classroom environment into a mini laboratory that encourages children to dare to try, fail, and improve themselves (Tipmontiane & Williams, 2022).

Strategic Organisation and Inclusive Education Commitment
The organization of the curriculum based on contextual thematic approaches such as the Sundanese cultural environment and the natural surroundings demonstrates the flexibility of the institution in implementing the Merdeka Belajar policy. The intracurricular structure strengthened by extracurricular activities such as angklung and swimming provides holistic motor and cognitive stimulation. Furthermore, the commitment of TK Islam Miftahul Fath toward inclusive education shows a high awareness of social justice and the right of every child to receive equitable educational services. Through holistic initial assessments and differentiated learning, the school is able to embrace the diverse characteristics of children including those with developmental barriers. Strategic partnerships with parents and medical personnel strengthen the support ecosystem necessary to ensure every child reaches their maximum potential according to their developmental phase (Gumiandari, 2021).

Determinants of Success and Implementation Barriers

Analysis of supporting factors indicates that teacher competence in creating a joyful learning atmosphere and harmonious communication with parents are the main pillars of successful STEM implementation. Broad opportunities provided to students to experiment outside the classroom increase their enthusiasm and self confidence in solving problems. However, this study also identifies several obstacles that need immediate resolution, particularly the limitation of modern learning media and the still limited understanding of parents toward innovative learning models. The lack of collaboration with external parties or technology experts also remains a challenge in expanding STEM horizons at the school. More intensive collaborative efforts are needed between the school, the foundation, and the community to provide more complete supporting facilities and continuous education for parents to align perceptions regarding the urgency of twenty first century skills for early childhood (Judijanto & Yusniar, 2025).

CONCLUSION

This study concludes that the implementation of the STEM approach through the Engineering Design Process (EDP) model at TK Islam Miftahul Fath Bandung has been effective in stimulating early childhood critical thinking skills. Instructional planning strategically integrates elements of religious values, identity formation, and science and technology literacy in alignment with the demands of 21st-century education. The program implementation is focused on the internalization of eight developmental dimensions, including critical reasoning and creativity, through meaningful and enjoyable exploratory activities. The utilization of EDP as a systematic framework has proven capable of transforming the teacher's role into that of a competent facilitator who guides children through stages of inquiry akin to young engineers. Effective questioning techniques and an interactive learning environment serve as key factors in fostering children's self-confidence and natural problem-solving abilities. The sustainability of this innovation largely depends on teachers' consistency in conducting reflective documentation, developing varied learning media both inside and outside the classroom, and strengthening collaborative synergy with parents to ensure holistic and sustainable child development.

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