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An Inquiry-Based Learning Approach in Early Childhood and Primary Education: Strengthening Foundational Concepts in Mathematics and Integrated Sciences

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ABSTRACT

This study examines the implementation of Inquiry-Based Learning (IBL) in early childhood and primary STEM education to enhance foundational competencies in mathematics and science. IBL emphasizes student-centered exploration, questioning, and problem-solving; however, its application in early education remains inconsistent due to various pedagogical and contextual challenges. This research employs a qualitative descriptive approach involving classroom observations, semi-structured interviews, and document analysis in selected early childhood and primary education settings. Data were analyzed using an interactive model consisting of data reduction, data display, and conclusion drawing, supported by triangulation to ensure validity. The findings indicate that IBL contributes to high student engagement, improved collaborative learning, and emerging critical thinking skills, although its implementation remains moderate due to limitations in teacher competence, resource availability, and curriculum constraints. The discussion highlights that integrated and well-supported IBL practices can significantly strengthen interdisciplinary learning in mathematics and science, but require sustained professional development and institutional support. In conclusion, the study affirms that an integrated IBL model has strong potential to improve early STEM learning outcomes when implemented through a holistic and context-sensitive approach.

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1. INTRODUCTION

Inquiry-Based Learning (IBL) has increasingly been recognized as a transformative pedagogical approach in early childhood and primary STEM education, emphasizing children's active engagement through questioning, exploration, and problem-solving. Unlike traditional teacher-centered instruction, IBL positions learners as active constructors of knowledge, fostering deeper understanding and meaningful learning experiences. In the context of early childhood and primary education, where foundational concepts in mathematics and science are developed, IBL plays a critical role in shaping cognitive, social, and emotional growth. However, despite its theoretical advantages and growing advocacy in educational discourse, the practical implementation of IBL remains uneven across educational settings. Many classrooms continue to rely on rote learning and teacher-dominated instruction, limiting opportunities for children to engage in inquiry processes that stimulate higher-order thinking. This discrepancy between pedagogical ideals and classroom realities highlights an urgent need to examine how IBL can be effectively integrated into early STEM education to achieve its intended outcomes (Kausar et al., 2024).

One of the central problems observed in early STEM education is the persistence of surface-level learning, where children often memorize concepts without understanding underlying principles. This issue is particularly evident in mathematics and science instruction, where abstract concepts require meaningful contextualization to be fully grasped. Traditional instructional approaches frequently fail to provide opportunities for exploration and experimentation, resulting in limited student engagement and reduced critical thinking skills. In contrast, IBL has been shown to enhance conceptual understanding by encouraging learners to investigate real-world phenomena and construct their own knowledge through guided inquiry. Nevertheless, the adoption of IBL is often constrained by systemic factors such as rigid curricula, limited instructional time, and insufficient teacher training. These challenges suggest that while IBL holds promise for improving STEM learning outcomes, its effectiveness depends heavily on the conditions under which it is implemented (Eti & Siğirtmaç, 2021).

In addition to conceptual limitations, another significant issue lies in the fragmented nature of STEM instruction at the early education level. Mathematics and science are frequently taught as separate subjects, with little integration between them, despite their inherently interconnected nature. This separation hinders the development of holistic understanding and reduces opportunities for students to apply knowledge across disciplines. Integrated STEM approaches within an inquiry-based framework can address this issue by providing contextualized learning experiences that connect mathematical reasoning with scientific inquiry. Activities such as experiments involving light and shadow or ecosystem exploration enable children to simultaneously engage with multiple domains of knowledge. However, existing practices often lack coherence and fail to systematically integrate these disciplines, pointing to a need for more structured and intentional implementation of integrated IBL models in early education (Kamarudin et al., 2022).

Furthermore, teacher preparedness emerges as a critical factor influencing the success of IBL in early STEM education. Many teachers, particularly at the early childhood and primary levels, report low confidence and limited competence in designing and facilitating inquiry-based activities. This is often due to insufficient professional development opportunities and a lack of exposure to IBL methodologies during pre-service training. As a result, teachers may revert to traditional instructional methods that are more familiar and easier to manage within constrained classroom environments. Research indicates that targeted training programs, including workshops, courses, and collaborative learning communities, can significantly enhance teachers' ability to implement IBL effectively. However, such initiatives are not always accessible or sustained, leading to inconsistent adoption of inquiry-based practices across educational contexts (Gong et al., 2025).

Another challenge that complicates the implementation of IBL is the limited availability of resources and supportive learning environments. Effective inquiry-based learning requires access to materials, tools, and spaces that facilitate exploration and experimentation. In many educational settings, particularly those with limited funding, such resources are scarce, restricting the scope and quality of inquiry activities. Additionally, the lack of digital tools and technological integration further constrains the potential of IBL to create engaging and interactive learning experiences. While digital simulations and educational technologies have been identified as valuable supports for inquiry-based instruction, their use remains uneven and often underutilized. Addressing these resource-related barriers is essential for ensuring that all students have equitable access to high-quality STEM education (Kotsis et al., 2025).

Despite these challenges, existing literature consistently highlights the positive impact of IBL on student learning outcomes in mathematics and science. Inquiry-based approaches have been shown to improve critical thinking, problem-solving skills, and collaborative learning, all of which are essential competencies for the 21st century. In mathematics education, for instance, open-ended and context-rich tasks encourage students to explore multiple solution pathways, thereby enhancing their reasoning abilities and engagement. Similarly, in science education, inquiry-based activities promote understanding of scientific concepts and processes by allowing students to actively participate in experimentation and observation. These findings underscore the potential of IBL to transform STEM education, provided that its implementation is supported by appropriate pedagogical and institutional frameworks (Fry et al., 2025).

However, a critical examination of the existing body of research reveals several gaps that warrant further investigation. First, while numerous studies have explored the benefits of IBL in either mathematics or science education, there is limited research focusing on the integration of these disciplines within an inquiry-based framework, particularly at the early childhood and primary levels. Second, many studies emphasize student outcomes without पर्याप्त attention to the contextual factors that influence the effectiveness of IBL, such as teacher beliefs, classroom environment, and institutional support. Third, there is a lack of longitudinal studies that examine the sustained impact of IBL on students' cognitive and socio-emotional development. These gaps indicate a need for more comprehensive and context-sensitive research that addresses the complexities of implementing IBL in diverse educational settings (Meitei et al., 2024).

In terms of novelty, this study seeks to contribute to the existing literature by proposing a more integrated and contextually grounded approach to IBL in early childhood and primary STEM education. Unlike previous studies that focus on isolated aspects of inquiry-based learning, this research emphasizes the interconnectedness of mathematics and science through integrated inquiry activities. It also considers the role of teacher professional development, resource availability, and classroom environment as key determinants of successful implementation. By adopting a holistic perspective, this study aims to provide a more nuanced understanding of how IBL can be effectively applied to enhance foundational STEM learning. Additionally, the study introduces innovative pedagogical strategies that combine play-based learning, storytelling, and problem-based approaches within an inquiry framework, thereby offering practical insights for educators and policymakers (Safitri, 2024).

Moreover, this research highlights the importance of creating supportive ecosystems that facilitate the implementation of IBL. Such ecosystems include not only classroom-level factors but also broader institutional and community support systems. Collaboration between schools and families, for instance, can reinforce inquiry-based learning by extending exploration beyond the classroom. Similarly, mentoring and peer collaboration among teachers can foster a culture of continuous professional growth and innovation. By addressing both micro- and macro-level factors, this study advances a more comprehensive model of IBL implementation that aligns with the complexities of real-world educational contexts. This approach represents a significant departure from traditional models that focus primarily on instructional techniques, thereby contributing to the advancement of knowledge in the field of early STEM education (Wang & Chen, 2025).

Based on the identified problems, research gaps, and proposed innovations, the primary objective of this study is to analyze and develop an integrated inquiry-based learning model that effectively enhances foundational mathematics and science competencies in early childhood and primary education. This objective is grounded in the need to bridge the gap between theoretical frameworks and practical implementation, ensuring that IBL can be applied in a manner that is both effective and sustainable. By achieving this objective, the study aims to provide valuable contributions to educational practice and policy, ultimately supporting the development of a more engaging, inclusive, and high-quality STEM education system for young learners (Asilevi et al., 2025).

2. METHOD

This study employs a qualitative research design with a descriptive-analytical approach to explore and develop an integrated inquiry-based learning (IBL) model in early childhood and primary STEM education. The qualitative approach is selected to capture in-depth insights into the implementation of IBL, particularly in understanding how mathematical and scientific concepts are constructed through inquiry processes in real classroom contexts. The research is conducted in selected early childhood education centers and primary schools that have begun to adopt or experiment with inquiry-based or STEM-integrated learning practices. Participants include early childhood educators, primary school teachers, and selected students, chosen through purposive sampling to ensure relevance to the research objective. Data collection techniques consist of classroom observations, semi-structured interviews, and document analysis. Classroom observations are conducted to identify instructional practices, student engagement, and the integration of inquiry processes in STEM activities. Semi-structured interviews with teachers are used to explore their pedagogical beliefs, experiences, and challenges in implementing IBL. Meanwhile, document analysis focuses on lesson plans, teaching materials, and curriculum documents to examine the extent to which inquiry-based and integrated STEM approaches are embedded in instructional design.

The data analysis process follows an interactive model consisting of data reduction, data display, and conclusion drawing. First, data reduction is carried out by organizing and coding the collected data to identify key themes related to inquiry-based learning implementation, integration of mathematics and science, and supporting or inhibiting factors. Second, data display is conducted through thematic matrices and narrative descriptions to facilitate pattern recognition and comparison across different data sources. Finally, conclusions are drawn through an iterative process, ensuring that findings are continuously verified against the data to maintain validity and credibility. Triangulation is applied by comparing data from observations, interviews, and documents to enhance the trustworthiness of the findings. Additionally, member checking is conducted by involving participants in validating the interpretations of the data. Through this systematic analytical process, the study aims to generate a comprehensive and contextually grounded model of integrated inquiry-based learning that is applicable and sustainable in early childhood and primary STEM education contexts.

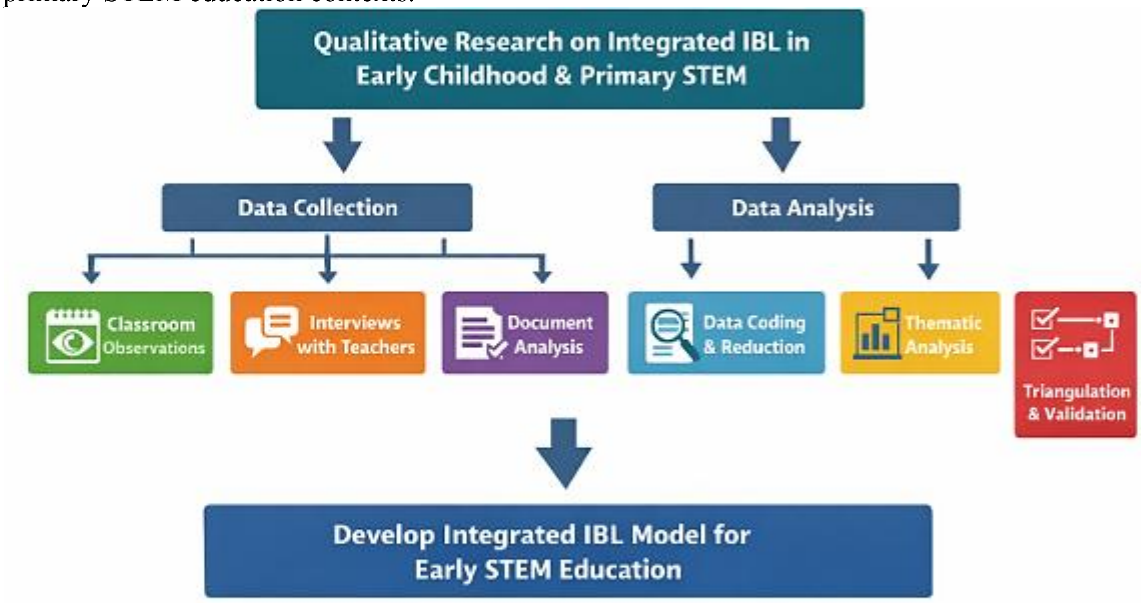

Figure 1. Diagram Conceptual Research

3. RESULTS AND DISCUSSION

The findings of this study were derived from classroom observations, interviews with teachers, and document analysis, focusing on the implementation of integrated inquiry-based learning (IBL) in early childhood and primary STEM education. The results highlight key aspects of instructional practices, teacher competencies, student engagement, and supporting as well as inhibiting factors. The synthesized data are presented in the following table to provide a structured overview of the main findings.

No.	Aspect of Analysis	Key Findings	Data Source	Interpretation Indicator
1	Instructional Practices	IBL implemented through exploration, questioning, and hands-on activities	Observation, Documents	Moderate–High implementation
2	Integration of Math–Science	Partial integration through contextual activities (e.g., experiments, play)	Observation, Lesson Plans	Moderate integration
3	Student Engagement	High enthusiasm, active participation, collaborative learning observed	Observation	High engagement
4	Critical Thinking & Problem Solving	quɲqDeveloping but not yet optimal across all students	Observation, Interviews	Moderate development
5	Teacher Competence in IBL	Varies; some teachers confident, others still rely on traditional methods	Interviews	Low–Moderate competence
6	Use of Learning Resources	Limited materials and digital tools in several classrooms	Observation, Documents	Low resource support
7	Professional Development Support	Training exists but not continuous or intensive	Interviews	Moderate support
8	Implementation Barriers	Time constraints, curriculum demands, lack of guidance	Interviews, Documents	High level of constraints
9	Supporting Factors	Collaborative environment, playful learning context, teacher motivation	Observation, Interviews	Strong supporting factors

The table indicates that the implementation of inquiry-based learning in early childhood and primary STEM education demonstrates promising outcomes, particularly in fostering student engagement and encouraging active participation. However, the integration of mathematics and science remains at a moderate level, suggesting that interdisciplinary approaches are not yet fully optimized. While students show emerging critical thinking and problem-solving abilities, these competencies are not consistently developed across all learning contexts. A significant challenge lies in the variability of teacher competence, as some educators still depend on traditional instructional methods due to limited training and confidence in applying IBL. Additionally, resource constraints and structural barriers, such as limited instructional time and rigid curricular demands, hinder the effective implementation of inquiry-based practices.

Despite these limitations, the presence of strong supporting factors—such as collaborative classroom environments, play-based learning strategies, and teacher motivation—indicates substantial potential for improving IBL implementation. The findings suggest that enhancing continuous professional development, improving access to learning resources, and strengthening curriculum support systems are critical steps toward optimizing integrated inquiry-based learning. Overall, the results reinforce the importance of adopting a holistic and context-sensitive approach to ensure that IBL can effectively enhance foundational mathematics and science competencies in early childhood and primary education.

Discussion

The findings of this study demonstrate that the implementation of Inquiry-Based Learning (IBL) in early childhood and primary STEM education has yielded meaningful yet uneven outcomes across several dimensions, including instructional practices, student engagement, teacher competence, and contextual support systems. In line with the research objective—to develop an integrated inquiry-based learning model that enhances foundational mathematics and science competencies—the discussion reveals that IBL has been partially successful in transforming traditional pedagogical approaches into more student-centered and exploratory learning environments. Classroom observations indicate that teachers have begun to incorporate inquiry elements such as questioning, exploration, and hands-on activities, which aligns with the theoretical premise that IBL fosters deeper conceptual understanding and active engagement. This finding corroborates previous studies emphasizing that inquiry-based approaches significantly enhance students' critical thinking, problem-solving abilities, and collaborative skills, ultimately leading to more meaningful learning experiences in early STEM education (Kausar et al., 2024).

However, the implementation of IBL in instructional practices remains at a moderate level, suggesting that while teachers are adopting inquiry strategies, these are not yet fully embedded into systematic pedagogical frameworks. This partial implementation can be attributed to the persistence of traditional teaching habits and limited pedagogical transformation. As highlighted in the data, some teachers continue to rely on direct instruction, particularly when addressing complex concepts in mathematics and science. This reflects a broader issue identified in the literature, where educators struggle to transition from teacher-centered to inquiry-oriented approaches due to entrenched beliefs and limited exposure to effective IBL models. Research by Eti and Siğirtmaç (2021) supports this observation, noting that although inquiry-based learning has clear benefits, its successful implementation requires a paradigm shift in teaching practices, which often takes time and sustained support.

The integration of mathematics and science within the IBL framework, as revealed in the findings, is still developing and remains inconsistent across classrooms. While some educators have successfully implemented contextual and playful activities—such as simple experiments, environmental observations, and manipulative-based tasks—these practices are not yet systematically integrated into a cohesive STEM framework. This partial integration limits the potential of IBL to foster interdisciplinary understanding, which is essential for developing holistic cognitive skills in young learners. The literature strongly supports the integration of STEM disciplines within inquiry-based approaches, highlighting that activities such as exploring light and shadow or engaging in ecological investigations can significantly enhance students' understanding of abstract scientific concepts while simultaneously strengthening mathematical reasoning (Kamarudin et al., 2022). Therefore, the current findings suggest a need for more structured models that explicitly link mathematics and science within inquiry-based learning contexts.

A key strength identified in this study is the high level of student engagement observed during inquiry-based activities. Students demonstrated enthusiasm, active participation, and collaborative interaction, indicating that IBL effectively creates a dynamic and motivating learning environment. This aligns with existing research emphasizing that inquiry-based learning fosters intrinsic motivation by allowing students to take ownership of their learning processes. According to Kotsis (2024), inquiry-based STEM activities not only improve conceptual understanding but also enhance students' willingness to engage in complex problem-solving tasks. The observed engagement in this study further supports the notion that early exposure to inquiry-based learning can cultivate positive attitudes toward mathematics and science, which are critical for long-term academic success.

Despite high engagement levels, the development of critical thinking and problem-solving skills among students was found to be moderate rather than optimal. This suggests that while students are actively participating in inquiry activities, the depth of cognitive processing may not yet reach higher-order thinking levels consistently. One possible explanation is that inquiry activities are not always scaffolded effectively to guide students toward deeper analysis and reflection. Effective IBL requires not only exploration but also structured guidance that helps learners formulate hypotheses, analyze data, and draw conclusions. As noted by Adeyele (2023), the effectiveness of inquiry-based learning in developing higher-order thinking skills depends on the quality of instructional design and the extent to which teachers facilitate reflective thinking processes. Therefore, enhancing the quality of inquiry tasks and providing appropriate scaffolding mechanisms are essential for maximizing the cognitive benefits of IBL.

Teacher competence emerges as a critical factor influencing the success of IBL implementation. The findings indicate significant variability in teachers' ability to design and facilitate inquiry-based learning, with some demonstrating confidence and creativity, while others remain dependent on traditional methods. This variation highlights the importance of professional development in supporting pedagogical transformation. Existing literature consistently emphasizes that targeted training programs, including workshops, collaborative learning communities, and practice-based experiences, are essential for developing teachers' inquiry-teaching competencies. Gong et al. (2025) argue that sustained professional development initiatives significantly improve teachers' confidence and ability to implement inquiry-based instruction effectively. Similarly, Strat et al. (2023) and Şensoy et al. (2024) highlight that continuous exposure to IBL practices enhances teachers' instructional design skills and fosters a deeper understanding of inquiry pedagogy.

The limited use of learning resources and digital tools identified in this study further constrains the effectiveness of IBL. Inquiry-based learning relies heavily on access to materials, tools, and technologies that support exploration and experimentation. In contexts where such resources are scarce, the scope of inquiry activities becomes restricted, limiting students' opportunities to engage in authentic learning experiences. This finding is consistent with previous research indicating that resource limitations are a major barrier to the implementation of IBL, particularly in under-resourced educational settings (Kausar et al., 2024). Moreover, the integration of digital tools and simulations has been shown to enhance inquiry-based learning by providing interactive and immersive experiences that facilitate conceptual understanding. Wang and Chen (2025) emphasize that digital technologies can significantly support inquiry processes by enabling students to visualize abstract concepts and conduct virtual experiments.

Another critical aspect highlighted in the findings is the role of professional development support, which was found to be moderate but insufficiently sustained. While some training opportunities are available, they are often short-term and lack continuity, limiting their impact on long-term pedagogical change. This aligns with the literature suggesting that effective professional development for IBL must be ongoing, collaborative, and supported by institutional frameworks. Fry et al. (2025) and Alsina et al. (2025) argue that sustained professional learning communities are essential for shifting teachers' beliefs and practices toward inquiry-oriented instruction. Without continuous support, teachers may struggle to maintain and refine their inquiry-based practices, leading to inconsistent implementation.

The study also identifies significant implementation barriers, including time constraints, curriculum pressures, and limited guidance on how to enact IBL effectively. These challenges reflect systemic issues within educational systems that prioritize standardized outcomes and rigid curricula over exploratory learning processes. As a result, teachers may feel constrained in their ability to implement inquiry-based approaches, even when they recognize their benefits. This finding is consistent with research by Meitei et al. (2024) and Selepe and Willemse (2025), which highlights that structural constraints often hinder the adoption of innovative pedagogies in early education. Addressing these barriers requires policy-level interventions that provide flexibility in curriculum design and allocate sufficient time for inquiry-based activities.

Despite these challenges, the presence of strong supporting factors offers promising opportunities for enhancing IBL implementation. The study highlights the importance of collaborative classroom environments, play-based learning strategies, and teacher motivation in facilitating inquiry-based learning. Playful and contextualized activities, such as storytelling, experiments, and real-world problem-solving tasks, create a supportive learning environment that encourages exploration and creativity. This aligns with research indicating that play-based and inquiry-driven approaches are particularly effective in early childhood education, as they align with children's natural learning processes. Safitri (2024) and Meitei et al. (2024) emphasize that integrating play into inquiry-based learning can simultaneously support mathematical reasoning and scientific understanding, making learning more engaging and meaningful.

Furthermore, the integration of innovative pedagogical approaches, such as storytelling combined with inquiry, play-based mathematics and coding, and problem-based STEAM learning, presents a significant opportunity for enhancing IBL implementation. These approaches not only support cognitive development but also foster creativity, collaboration, and confidence among both students and teachers. Nhase and Dube (2023) highlight that storytelling-based inquiry creates a non-threatening and engaging context for introducing scientific concepts, while Habib (2025) emphasizes that problem-based STEAM approaches enhance critical inquiry and teacher confidence. These findings suggest that adopting diverse and flexible instructional strategies can significantly improve the effectiveness of IBL in early STEM education.

In addressing the research objective, the findings of this study underscore the importance of adopting a holistic and integrated approach to inquiry-based learning in early childhood and primary STEM education. The development of an effective IBL model requires not only the integration of mathematics and science but also the alignment of instructional practices, teacher competencies, resource availability, and institutional support systems. By considering these interconnected factors, the study contributes to a more comprehensive understanding of how IBL can be effectively implemented to enhance foundational STEM competencies.

In conclusion, this study provides valuable insights into the implementation of inquiry-based learning in early childhood and primary STEM education, highlighting both its potential and its challenges. While IBL has been shown to enhance student engagement, conceptual understanding, and collaborative learning, its effectiveness is influenced by a range of contextual factors, including teacher competence, resource availability, and systemic constraints. The findings suggest that addressing these challenges through sustained professional development, improved resource support, and flexible curriculum frameworks is essential for optimizing the impact of IBL. Ultimately, the study reinforces the need for a comprehensive and context-sensitive approach to implementing inquiry-based learning, ensuring that it can effectively support the development of critical thinking, problem-solving, and foundational STEM skills in young learners (Asilevi et al., 2025).

4. CONCLUSION

In conclusion, this study demonstrates that the development of an integrated Inquiry-Based Learning (IBL) model in early childhood and primary STEM education has significant potential to enhance foundational competencies in mathematics and science, particularly in fostering student engagement, collaborative learning, and emerging critical thinking skills. However, the findings also reveal that the effectiveness of IBL remains contingent upon several interrelated factors, including the level of teacher competence, the availability of learning resources, the degree of interdisciplinary integration, and the presence of sustained professional and institutional support. While inquiry-based practices have begun to shift classrooms toward more student-centered learning environments, their implementation is still partial and requires systematic strengthening through continuous teacher training, improved resource provision, and more flexible curricular frameworks. Therefore, achieving the intended outcomes of integrated IBL necessitates a holistic and context-sensitive approach that aligns pedagogical innovation with structural support systems, ensuring that inquiry-based strategies can be effectively and sustainably embedded in early STEM education.

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