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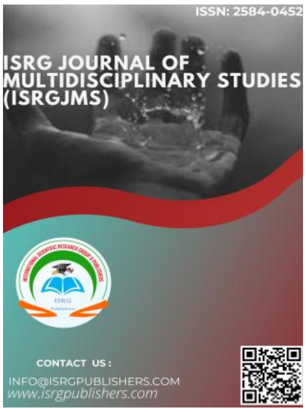

IMPLEMENTING INQUIRY-BASED LEARNING STRATEGIES IN MATHEMATICS TO FOSTER MEANINGFUL LEARNING

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Abstract

Mathematics education is expected to develop students' conceptual understanding, reasoning, and problem-solving abilities rather than merely procedural fluency. However, mathematics instruction in many educational contexts continues to emphasize memorization of formulas and the reproduction of teacher-demonstrated procedures, limiting students' opportunities to construct meaningful mathematical understanding. Inquiry-Based Learning (IBL) offers a promising pedagogical alternative by positioning students as active participants in questioning, investigating, conjecturing, reasoning, and reflecting on mathematical ideas. This paper aims to conceptually examine the role of inquiry-based learning in promoting meaningful learning in mathematics education. Drawing on constructivist perspectives and theories of meaningful learning, the paper analyzes the pedagogical processes through which inquiry activities facilitate the construction of mathematical knowledge. The discussion highlights that meaningful mathematical learning emerges not simply from student exploration but from the integration of questioning, mathematical investigation, representation, reasoning, communication, and reflection supported by appropriate teacher scaffolding. The paper further examines the pedagogical phases of mathematical inquiry, the relationship between inquiry and conceptual understanding, and major challenges associated with its classroom implementation. The analysis suggests that the effectiveness of inquiry-based mathematics learning depends on a balance between student autonomy and structured instructional guidance. Rather than functioning as completely unguided discovery, effective inquiry requires carefully designed mathematical tasks, productive questioning, collaborative discourse, and opportunities for reflection and formalization. This paper contributes a conceptual perspective that positions inquiry as a pedagogical pathway connecting active mathematical exploration with meaningful understanding, reasoning, and problem solving. The findings have implications for mathematics teachers, curriculum designers, and researchers seeking to promote deeper and more student-centered mathematics learning.

Keywords: *inquiry-based learning; mathematics education; meaningful learning; mathematical reasoning; conceptual understanding; problem solving*

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INTRODUCTION

Mathematics plays a fundamental role in the development of individuals and societies in an increasingly complex, information-rich, and technology-driven world. Beyond its traditional function as a discipline concerned with numbers, formulas, and calculations, mathematics provides essential tools for logical reasoning, critical thinking, problem solving, and decision making. Contemporary mathematics education therefore emphasizes that learning mathematics should enable students not only to perform procedures accurately but also to understand mathematical relationships, communicate ideas, construct arguments, and apply knowledge to unfamiliar situations (National Council of Teachers of Mathematics [NCTM], 2000; Boaler, 2022). Mathematical competence has consequently become an essential component of students' preparation for participation in academic, professional, and everyday contexts. Despite the strategic importance of mathematics, mathematics learning continues to present significant challenges across different educational contexts. One persistent problem concerns the gap between students' procedural performance and their conceptual understanding. Students may be able to perform routine calculations or reproduce algorithms demonstrated by teachers, yet encounter difficulties when confronted with unfamiliar problems requiring interpretation, reasoning, justification, or the connection of multiple mathematical concepts. This phenomenon suggests that the ability to obtain a correct answer does not necessarily indicate meaningful understanding of the mathematical principles underlying a procedure (Hiebert & Lefevre, 1986; Rittle-Johnson et al., 2015). Consequently, mathematics education needs to move beyond an exclusive emphasis on procedural fluency toward learning experiences that promote conceptual understanding and flexible mathematical thinking. Traditional instructional practices may contribute to this challenge when mathematics is predominantly presented as a collection of rules, formulas, and procedures to be memorized. In many conventional classrooms, learning commonly follows a sequence in which teachers explain a concept, demonstrate examples, and subsequently ask students to complete similar exercises. Although explicit instruction can be useful for introducing mathematical procedures, an excessive dependence on teacher-centered knowledge transmission may limit opportunities for students to explore mathematical relationships and construct their own understanding (Hattie, 2023; Artzt et al., 2024). Students may consequently become dependent on teacher demonstrations and perceive mathematics as a fixed body of knowledge rather than as a dynamic process of investigation, reasoning, and problem solving. The distinction between procedural knowledge and conceptual understanding is particularly important in mathematics education. Conceptual knowledge refers to understanding the relationships among mathematical ideas, whereas procedural knowledge concerns knowledge of rules, algorithms, and sequences of actions used to solve problems (Hiebert & Lefevre, 1986). Effective mathematics learning requires an interconnected development of both forms of knowledge. Students need to understand not only *how* to perform a procedure but also *why* the procedure works and under what circumstances it can be appropriately applied. Research has demonstrated that conceptual and procedural knowledge develop in iterative and mutually supportive ways, suggesting that meaningful mathematics instruction should create opportunities for students to connect procedures with underlying concepts (Rittle-Johnson et al., 2015).The concept of meaningful learning provides an important theoretical foundation for addressing this challenge. Meaningful learning occurs when new knowledge is connected substantively and non-arbitrarily with relevant concepts already existing in learners' cognitive structures (Ausubel, 1968; Novak, 2010). In contrast to rote learning, meaningful learning involves the active construction of relationships between new information and prior knowledge. Within mathematics education, meaningful learning can be reflected in students' ability to recognize relationships among concepts, interpret multiple representations, explain mathematical procedures, justify their reasoning, and transfer knowledge to new situations. Thus, meaningful learning involves more than remembering mathematical facts; it requires students to organize mathematical ideas into coherent conceptual structures. Constructivist perspectives further support the importance of active knowledge construction in mathematics learning. From a constructivist viewpoint, knowledge is not simply transferred intact from teachers to students but is actively constructed through learners' engagement with experiences, ideas, and social interactions (Piaget, 1970; Vygotsky, 1978). Learning environments should therefore provide students with opportunities to explore, question, test ideas, communicate their thinking, and reflect upon their experiences. In mathematics classrooms, these activities enable students to participate actively in the process of mathematical sense-making rather than merely receiving finished explanations. The teacher's role consequently extends beyond transmitting information toward designing learning environments that support students' intellectual development. One instructional approach that aligns strongly with these principles is Inquiry-Based Learning (IBL). Inquiry-based learning positions students as active participants in the learning process and encourages them to investigate questions, problems, and phenomena systematically. Students are expected to engage in activities such as questioning, problem identification, hypothesis generation, investigation, evidence analysis, explanation, and reflection (Pedaste et al., 2015). Rather than immediately receiving complete explanations from teachers, learners are encouraged to explore ideas and construct understanding through systematic intellectual activity. Inquiry-based learning is therefore closely associated with the development of higher-order thinking because students must analyze information, evaluate alternative possibilities, and construct reasoned conclusions. The relevance of inquiry-based learning becomes particularly significant in mathematics education because mathematical activity itself involves processes of exploration, conjecturing, reasoning, verification, and generalization. Mathematics should not be understood solely as a collection of established facts but also as a discipline characterized by inquiry into patterns, relationships, and structures. When students are provided opportunities to investigate mathematical situations, formulate conjectures, test possible relationships, and justify conclusions, they can experience mathematics as an active process of knowledge construction. Such experiences may contribute to the development of deeper conceptual understanding and mathematical reasoning (NCTM, 2000; Russo & Hopkins, 2019). Inquiry-based learning has been associated with several positive educational outcomes. Research suggests that inquiry-oriented instruction can support students' academic achievement while also promoting active cognitive engagement and higher-order thinking processes (Siregar et al., 2020). Inquiry encourages students to become involved in problem identification and solution development rather than simply following predetermined procedures. In mathematics classrooms, this approach can provide opportunities for students to explore multiple solution strategies,

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identify patterns, construct representations, and explain their reasoning. These activities are particularly important because mathematical understanding develops through engagement with relationships and structures rather than through memorization alone. However, the implementation of inquiry-based learning should not be interpreted as completely unguided discovery. One of the most important debates surrounding inquiry concerns the appropriate balance between learner autonomy and instructional guidance. Students who are provided with complex problems without sufficient conceptual or strategic support may experience confusion and cognitive overload. Conversely, excessive teacher direction can reduce inquiry to a sequence of predetermined activities in which students merely follow instructions without engaging in genuine intellectual exploration. Research on inquiry learning therefore emphasizes the importance of structured or guided inquiry, in which students are provided with appropriate scaffolding while maintaining opportunities for autonomy and knowledge construction (Hmelo-Silver et al., 2007; Lazonder & Harmsen, 2016).

Teacher scaffolding is particularly important in mathematics learning because mathematical ideas often involve abstract concepts and symbolic representations. Students may successfully identify patterns through experimentation but still require support to formulate generalizations and construct formal mathematical arguments. The transition from informal exploration to formal mathematical understanding requires purposeful teacher intervention. Teachers need to provide productive questions, encourage students to compare strategies, facilitate mathematical discourse, and help learners connect their findings with established mathematical concepts. Thus, effective inquiry does not eliminate the role of the teacher but transforms the teacher from an authoritative transmitter of knowledge into a facilitator of students' mathematical thinking (Artzt et al., 2024). The quality of mathematical tasks is another critical factor influencing the effectiveness of inquiry-based learning. Not all mathematical problems create opportunities for meaningful exploration. Routine exercises requiring direct application of a previously demonstrated algorithm may reinforce procedural fluency but offer limited opportunities for conjecturing, reasoning, and justification. In contrast, cognitively demanding and challenging mathematical tasks can encourage students to investigate relationships, generate multiple strategies, and construct arguments. Research has shown that allowing students to engage with challenging mathematical tasks before receiving direct instruction can create valuable opportunities for mathematical thinking and conceptual development (Russo & Hopkins, 2019). Therefore, inquiry-oriented mathematics instruction requires careful consideration of task design and the intellectual demands placed on students. Mathematical discourse also represents an essential component of inquiry-based learning. During inquiry activities, students need opportunities to articulate their thinking, communicate solution strategies, question assumptions, and evaluate the reasoning of others. Mathematical communication enables learners to externalize their ideas and receive feedback that can contribute to conceptual refinement. Through collaborative discussion, students may encounter alternative perspectives and recognize that mathematical problems can often be approached using multiple representations and strategies. These processes support the development of mathematical argumentation and contribute to a classroom culture in which understanding is constructed socially as well as individually (NCTM, 2000; Vygotsky, 1978). Inquiry-based learning also has the potential to strengthen mathematical reasoning and problem-solving abilities. Mathematical reasoning involves identifying relationships, formulating conjectures, constructing arguments, and drawing logical conclusions. Problem solving requires students to understand unfamiliar situations, develop strategies, evaluate possible solutions, and reflect on their approaches. These competencies cannot be fully developed through repetitive practice of routine algorithms alone. Students require opportunities to encounter non-routine problems that challenge them to make decisions about mathematical strategies and justify their conclusions (Roebyanto & Harmini, 2017; Boaler, 2022). Inquiry provides a pedagogical context in which these intellectual processes become integral components of learning. Nevertheless, implementing inquiry-based learning in authentic mathematics classrooms remains challenging. Teachers may encounter constraints related to limited instructional time, extensive curriculum requirements, classroom management, differences in students' prior knowledge, and conventional assessment systems that emphasize final answers rather than learning processes. Students who are accustomed to passive learning may initially experience difficulties when asked to formulate questions, generate hypotheses, or communicate mathematical reasoning. Similarly, teachers may require substantial pedagogical knowledge to determine when to intervene and how much guidance should be provided. These challenges demonstrate that the effectiveness of inquiry-based learning depends not merely on adopting a particular instructional syntax but on the quality of pedagogical design and implementation (Pedaste et al., 2015; Lazonder & Harmsen, 2016). Previous studies have provided valuable evidence regarding the effectiveness and phases of inquiry-based learning. Pedaste et al. (2015), for example, synthesized the inquiry cycle into interconnected processes involving orientation, conceptualization, investigation, conclusion, and discussion. Meta-analytic evidence has also indicated that inquiry learning can produce positive learning outcomes, particularly when appropriate guidance is incorporated into the instructional process (Lazonder & Harmsen, 2016). Similarly, research specifically addressing mathematics education has reported positive relationships between inquiry-oriented learning and students' mathematics achievement and cognitive engagement (Siregar et al., 2020). These findings provide an important foundation for understanding inquiry as a potentially powerful pedagogical approach. However, an important conceptual issue remains. Inquiry is frequently discussed primarily in terms of instructional phases or its measurable effects on learning outcomes. Comparatively less attention has been directed toward explaining the pedagogical and cognitive mechanisms through which inquiry activities contribute to meaningful mathematical learning. Active participation alone does not automatically produce conceptual understanding. Students may engage in exploration without successfully connecting their experiences to formal mathematical concepts. Similarly, discovering a pattern does not necessarily lead to meaningful learning unless students are encouraged to explain, justify, generalize, and reflect upon their findings. Therefore, the critical issue is not simply whether inquiry should be implemented but how inquiry processes can be pedagogically organized to facilitate the construction of meaningful mathematical understanding. This conceptual gap is particularly relevant because meaningful learning requires the integration of new knowledge with existing cognitive structures (Ausubel, 1968; Novak, 2010). Inquiry activities can provide experiences for exploration, but these experiences must subsequently be interpreted and connected with mathematical concepts. The processes of representation, reasoning,

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communication, and reflection may therefore function as important bridges between exploration and meaningful understanding. Without these processes, inquiry risks becoming activity-oriented rather than conceptually oriented. Accordingly, this paper aims to provide a conceptual analysis of inquiry-based learning as a pedagogical pathway toward meaningful mathematics learning. The discussion integrates theoretical perspectives on constructivism and meaningful learning with principles of inquiry-based instruction and mathematical reasoning. Rather than positioning inquiry as completely independent student discovery, this paper emphasizes the importance of structured exploration supported by purposeful teacher scaffolding. More specifically, this paper addresses the following questions: (1) What theoretical foundations support the use of inquiry-based learning in mathematics education? (2) What pedagogical processes characterize effective inquiry-based mathematics learning? (3) How does inquiry contribute to the development of meaningful mathematical understanding, reasoning, and problem-solving abilities? and (4) What challenges and instructional conditions should be considered to support its effective implementation? The contribution of this paper lies in developing an integrated conceptual perspective that connects inquiry activities with the processes underlying meaningful mathematical learning. This paper argues that meaningful mathematical learning does not emerge solely from student exploration but through an interconnected process of questioning, conjecturing, investigating, representing, reasoning, communicating, and reflecting. Within this framework, the teacher functions as a designer of learning environments and a facilitator who provides appropriate intellectual scaffolding to support students in connecting informal exploration with formal mathematical knowledge.The discussion is expected to contribute both theoretically and practically to mathematics education. Theoretically, it provides a framework for understanding the relationship between inquiry processes and meaningful mathematical learning. Practically, it offers pedagogical considerations for teachers seeking to design learning experiences that promote deeper conceptual understanding, mathematical reasoning, and active student engagement. For researchers, the paper identifies the need for further investigation into the mechanisms and instructional conditions through which inquiry can most effectively support meaningful learning. Ultimately, transforming mathematics learning requires more than replacing conventional instructional methods with new classroom activities. A meaningful transformation requires a change in how students experience mathematical knowledge itself. Mathematics should not be encountered merely as a collection of formulas and rules to be memorized but as a domain of inquiry in which learners explore relationships, construct arguments, test ideas, and develop understanding. Inquiry-based learning offers a potential pathway toward this transformation by connecting active exploration with reasoning and reflection. When carefully designed and supported, inquiry can help students move beyond simply performing mathematical procedures toward understanding mathematical ideas meaningfully.

RESULT AND DISCUSSION

Theoretical Foundations of Inquiry-Based Learning and Meaningful Learning

Inquiry-Based Learning (IBL) has gained increasing attention as a student-centered pedagogical approach designed to promote active engagement, conceptual understanding, and higher-order thinking. Rather than positioning students as passive recipients of mathematical knowledge, inquiry-oriented learning engages them in questioning, exploring, identifying patterns, constructing explanations, and evaluating mathematical ideas. Recent research indicates that the effectiveness of inquiry-based learning is closely associated with the extent to which students are cognitively engaged in constructing and refining knowledge rather than merely participating in learning activities (Koskinen & Pitkäniemi, 2022; Harleni et al., 2025). Thus, the fundamental value of inquiry lies not simply in making learning activities more interactive but in creating intellectual opportunities for students to construct mathematical meaning. Contemporary perspectives on mathematics education increasingly emphasize the importance of active knowledge construction. Students learn mathematics meaningfully when they are able to establish relationships among concepts, procedures, representations, and problem situations. A recent synthesis by Koskinen and Pitkäniemi (2022) demonstrated that meaningful learning in mathematics is promoted through contextual, concrete, and social approaches, particularly when student activities are supported by appropriate guidance and feedback. This finding is important because it suggests that active learning alone is insufficient; meaningful learning depends on how students interpret experiences, connect ideas, and receive pedagogical support during the learning process. Within inquiry-based learning, knowledge construction begins with intellectual uncertainty. Students encounter questions or problems for which the solution is not immediately apparent and are subsequently encouraged to explore possible relationships and develop explanations. In mathematics, this process may involve identifying patterns, comparing quantities, generating multiple representations, formulating conjectures, and testing mathematical ideas. Such activities encourage students to move beyond the reproduction of predetermined procedures and engage with mathematics as a process of investigation. Recent reviews of inquiry-oriented mathematics instruction have similarly emphasized that inquiry creates opportunities for students to formulate explanations through exploration while being supported by teacher scaffolding (Wang et al., 2023). The concept of meaningful learning is particularly relevant to this process. Meaningful mathematics learning occurs when students are able to develop coherent relationships among mathematical ideas rather than memorizing isolated formulas or algorithms. Koskinen and Pitkäniemi (2022) argue that meaningful learning in mathematics is associated with instructional approaches that connect learning with relevant contexts, concrete experiences, social interaction, and purposeful teacher guidance. Therefore, meaningful learning should not be understood simply as the acquisition of correct mathematical knowledge but as the development of an interconnected conceptual structure that enables students to interpret, explain, and apply mathematical ideas across situations. This perspective is closely related to contemporary discussions concerning conceptual understanding. Mathematics learning requires more than procedural competence because students must understand the relationships that give mathematical procedures their meaning. Recent systematic reviews of innovative instructional approaches in mathematics education have shown that student-centered models, including inquiry-based learning, can support conceptual understanding and higher-order thinking when learning tasks require exploration and reasoning rather than routine procedural reproduction (Lethulur et al., 2025). Consequently, inquiry can provide an important pedagogical environment for connecting mathematical procedures with the conceptual structures underlying

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them. An important characteristic of inquiry-based mathematics learning is the emphasis on epistemic activity. Students are not merely asked to complete tasks but are encouraged to investigate how mathematical knowledge can be developed and justified. This may involve asking why a particular pattern occurs, determining whether a conjecture is always true, comparing alternative solution strategies, and constructing mathematical arguments. Such activities position mathematical reasoning as an integral component of learning. Recent research on inquiry-based mathematics education has highlighted the importance of engaging learners with processes that resemble authentic mathematical practices, including conjecturing, defining relationships, and constructing explanations (Evans & Dietrich, 2022). However, this perspective must be balanced with evidence indicating that authentic mathematical exploration requires appropriate pedagogical structure, particularly for learners who are still developing foundational knowledge For this reason, contemporary inquiry-based learning should not be equated with completely unguided discovery. The effectiveness of inquiry depends substantially on the availability and quality of instructional guidance. A recent meta-analysis examining inquiry-based learning outcomes found that the effects of inquiry vary according to instructional design, student engagement, and educational context (Harleni et al., 2025). Similarly, research syntheses on meaningful mathematics learning emphasize the importance of teacher guidance, immediate feedback, and purposeful communication during student-centered learning activities (Koskinen & Pitkäniemi, 2022). These findings suggest that productive inquiry requires a balance between student autonomy and pedagogical support. Scaffolding therefore represents a central theoretical mechanism connecting inquiry with meaningful learning. In inquiry-based environments, scaffolding can support students without removing the intellectual responsibility of solving problems. Teachers may provide guiding questions, prompts, representations, partially structured tasks, or opportunities for collaborative discussion. A recent systematic review of scaffolding in mathematics education found that scaffolding strategies can support conceptual understanding by providing gradual assistance that is responsive to students' levels of understanding (Saputra et al., 2024). Similarly, literature on scaffolding in inquiry learning identifies questioning and prompts as important mechanisms for guiding students through investigation while maintaining their active role in knowledge construction (Purtadi et al., 2024). The importance of scaffolding becomes particularly evident when students encounter complex or unfamiliar mathematical problems. Without appropriate support, inquiry may result in unproductive exploration in which students become confused about the purpose of the task or unable to connect observations with mathematical concepts. Conversely, excessive teacher intervention may transform inquiry into a sequence of predetermined instructions. Effective scaffolding therefore requires teachers to make careful decisions regarding when and how support should be provided. The purpose is not to simplify the intellectual challenge completely but to provide temporary assistance that enables students to progress toward more sophisticated mathematical understanding (Saputra et al., 2024). Teacher questioning constitutes another important mechanism in inquiry-oriented mathematics learning. Questions can direct students' attention toward mathematical relationships without immediately revealing solution procedures. Productive questions encourage learners to explain their reasoning, compare alternative strategies, justify claims, and reflect on the validity of conclusions. Recent literature on inquiry pedagogy has emphasized that inquiry questions should stimulate meaningful and challenging mathematical problem solving rather than merely guide students toward predetermined answers (Professional Learning Interventions for Inquiry-Based Pedagogies in Primary Classrooms, 2025). In this sense, questioning functions as intellectual scaffolding that supports the development of mathematical reasoning. Meaningful learning also requires students to communicate and reflect upon their mathematical ideas. Exploration alone does not guarantee conceptual development because students may identify patterns without understanding why those patterns occur. Mathematical communication provides opportunities for learners to articulate their reasoning and make implicit ideas explicit. Through discussion, students can encounter alternative perspectives, compare strategies, and revise their understanding. Koskinen and Pitkäniemi (2022) emphasized the importance of social interaction and teacher-directed communication in supporting meaningful mathematics learning. Thus, communication should be viewed not simply as a means of presenting answers but as part of the cognitive process through which mathematical understanding is constructed. Reflection provides a further bridge between inquiry activity and conceptual understanding. During reflection, students reconsider the strategies they have used, evaluate the validity of their conclusions, and connect newly developed ideas with prior mathematical knowledge. Reflection enables students to move from isolated problem-solving experiences toward more general mathematical understanding. This process is particularly important in inquiry because exploration can produce diverse observations and strategies. Without opportunities for synthesis and reflection, students may complete an activity without recognizing the broader mathematical principles embedded within it. The relationship between inquiry and meaningful learning can therefore be conceptualized as a progressive process rather than a direct causal relationship. Inquiry creates an initial condition in which students encounter intellectual problems and actively investigate mathematical relationships. However, meaningful learning emerges through subsequent processes of interpretation, representation, reasoning, communication, and reflection. Teacher scaffolding operates throughout these processes by supporting students without replacing their intellectual agency. This perspective helps explain why the effectiveness of inquiry-based learning varies across instructional contexts: inquiry is not a single instructional activity but a complex pedagogical system involving task design, student engagement, teacher guidance, and opportunities for conceptual consolidation. Recent research supports the view that inquiry-based learning can positively influence learning outcomes while emphasizing the importance of implementation quality. Harleni et al. (2025), through a meta-analysis of studies published between 2020 and 2024, reported a positive overall effect of inquiry-based learning on student learning outcomes, with instructional design and student engagement identified as important moderating factors. In mathematics education, systematic reviews have similarly reported that inquiry-oriented approaches can contribute to conceptual understanding, critical thinking, motivation, and problem-solving abilities (Lethulur et al., 2025). These findings reinforce the argument that inquiry has considerable pedagogical potential but should not be implemented as a universal formula independent of context. The theoretical relationship between inquiry and meaningful learning can consequently be summarized through several interconnected processes. First, meaningful mathematical problems stimulate curiosity and cognitive engagement. Second, students explore

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mathematical situations and generate initial ideas or conjectures. Third, representations and investigations enable students to identify patterns and relationships. Fourth, reasoning and justification help transform observations into mathematically defensible conclusions. Fifth, communication allows students to articulate and evaluate their thinking. Finally, reflection supports the integration of new understanding with existing mathematical knowledge. Throughout these processes, scaffolding functions as a pedagogical mechanism that maintains an appropriate balance between exploration and guidance. Based on this perspective, inquiry-based mathematics learning should not be understood merely as an instructional method designed to increase classroom activity. Its theoretical significance lies in its capacity to organize mathematical learning as a process of knowledge construction. Students are encouraged to experience mathematics not simply as a body of established procedures but as a system of relationships that can be explored, questioned, justified, and generalized. Meaningful learning emerges when these exploratory experiences are systematically connected with conceptual understanding. Therefore, the integration of inquiry and meaningful learning offers an important direction for contemporary mathematics education. Inquiry provides the conditions for active intellectual engagement, while meaningful learning provides the cognitive orientation that ensures exploration develops into coherent understanding. The connection between the two depends on the quality of mathematical tasks, the nature of teacher scaffolding, opportunities for reasoning and communication, and structured reflection. These elements collectively form the theoretical foundation for understanding inquiry-based learning as a pedagogical pathway toward meaningful mathematical understanding.

Inquiry-Based Learning in Mathematics Education: Characteristics and Pedagogical Processes

Inquiry-Based Learning in mathematics education should be understood as more than a general instructional approach that encourages students to become active. Its distinctive characteristic lies in the way students engage with mathematical ideas, relationships, structures, and arguments. While inquiry-based learning in other disciplines may involve empirical observation and experimentation with physical phenomena, mathematical inquiry primarily involves investigating patterns, identifying relationships, constructing representations, formulating conjectures, and developing logical justifications. Therefore, the implementation of inquiry in mathematics requires pedagogical processes that support students in moving from exploration toward abstraction and formal mathematical understanding. Recent developments in mathematics education emphasize that students should experience mathematics as an active process of sense-making rather than as a fixed collection of rules and procedures. Mathematical learning becomes more meaningful when students are encouraged to investigate why mathematical relationships occur, explore alternative strategies, and construct explanations for their conclusions. Inquiry-oriented learning provides opportunities for students to engage in these processes by positioning mathematical problems as starting points for investigation rather than simply as exercises to be completed after instruction. Research on student-centered mathematics learning has shown that learning environments emphasizing exploration and problem solving can contribute to the development of conceptual understanding and higher-order thinking when students are supported in interpreting and reflecting upon their experiences (Koskinen & Pitkäniemi, 2022; Lethulur et al., 2025). A fundamental characteristic of mathematical inquiry is the presence of intellectually challenging questions. Inquiry begins when students encounter a mathematical situation that cannot be resolved immediately through the direct application of a familiar algorithm. Such situations create what may be described as productive uncertainty, encouraging students to explore available information and consider possible solution strategies. The purpose of these questions is not merely to increase the difficulty of learning but to stimulate students' intellectual engagement with mathematical relationships. A productive inquiry task should therefore invite students to think, investigate, and make decisions rather than simply recall previously memorized procedures. The nature of mathematical questions strongly influences the quality of inquiry. Closed questions with predetermined solution paths may limit opportunities for exploration, whereas open or cognitively demanding problems can encourage students to generate multiple approaches and compare different mathematical ideas. However, openness alone does not guarantee meaningful inquiry. Tasks must remain mathematically purposeful and connected to clearly identifiable conceptual goals. Recent discussions of inquiry pedagogy emphasize that effective inquiry tasks require an appropriate balance between intellectual challenge and instructional accessibility so that students are encouraged to investigate without becoming disengaged due to excessive complexity (Harleni et al., 2025). Problem formulation is another important characteristic of inquiry-based mathematics learning. Students should not always encounter mathematical problems as completely predefined questions with predetermined procedures. Depending on their level of readiness, learners can be encouraged to identify relevant mathematical questions within a given situation. For example, students may observe a numerical pattern and subsequently formulate questions concerning how the pattern develops, whether the relationship remains consistent, or how it can be represented algebraically. This process encourages students to develop ownership of mathematical problems and positions questioning as an essential component of mathematical thinking. The process of conjecturing represents a particularly distinctive feature of mathematical inquiry. A conjecture is a tentative mathematical statement developed on the basis of observed patterns or relationships that requires further examination and justification. Students may generate conjectures after exploring numerical examples, visual representations, geometric constructions, or real-world situations. However, identifying a pattern is only the beginning of mathematical inquiry. Students need to examine whether the pattern is consistently valid, identify possible exceptions, and develop arguments that explain why the relationship occurs. The transition from observation to justification represents an important movement from empirical exploration toward mathematical reasoning. Mathematical representations play a central role in supporting this transition. Students often develop understanding through multiple forms of representation, including concrete objects, diagrams, tables, graphs, numerical expressions, and symbolic notation. During inquiry, representations function not merely as illustrations but as cognitive tools that enable students to explore relationships and communicate ideas. A student investigating a proportional relationship, for instance, may begin with a contextual situation, organize information into a table, construct a graphical representation, and eventually develop an algebraic expression. The movement across representations enables learners to recognize structural relationships that may not be immediately visible within a single form of representation. The use of multiple representations is particularly important because mathematical understanding involves recognizing equivalence and

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relationships across different forms. Inquiry-oriented instruction can encourage students to compare representations and discuss what each representation reveals about a mathematical situation. Such activities help students move beyond superficial manipulation of symbols and develop a deeper understanding of the concepts represented. Recent perspectives on meaningful mathematics learning emphasize that conceptual development is strengthened when students are supported in connecting abstract mathematical ideas with concrete, visual, symbolic, and contextual representations (Koskinen & Pitkäniemi, 2022). Investigation constitutes the central activity through which students explore mathematical questions and test their ideas. Mathematical investigation may involve generating examples, manipulating variables, constructing diagrams, using technological tools, organizing data, or comparing alternative solution strategies. Unlike routine exercises, investigation does not assume that students already know the exact procedure required to obtain a solution. Students are required to make decisions regarding which strategies to use and evaluate whether their approaches are mathematically valid. This intellectual responsibility represents one of the primary mechanisms through which inquiry can support the development of autonomy and mathematical reasoning.

However, mathematical investigation should not be confused with trial-and-error activity without conceptual direction. Effective inquiry requires students to systematically examine relationships and evaluate evidence. Teachers therefore need to support learners in documenting observations, explaining patterns, and connecting particular findings with broader mathematical principles. Scaffolding can be provided through questions such as “What do you notice?”, “Does this relationship always occur?”, “Can you represent this idea differently?”, or “How can you justify your conclusion?” Such questions encourage students to move beyond obtaining answers toward examining the mathematical reasoning underlying their solutions. Reasoning and justification distinguish mathematical inquiry from simple exploratory activity. Students may observe that a particular pattern appears repeatedly, but mathematical understanding requires them to explain why the pattern occurs. This process involves constructing logical arguments and evaluating the validity of conclusions. Inquiry-based learning therefore creates opportunities for students to develop mathematical reasoning by requiring them to support claims with evidence. Rather than asking only whether an answer is correct, inquiry-oriented classrooms should encourage questions concerning why a solution works and whether the reasoning can be generalized. The importance of justification is particularly evident when students encounter multiple solution strategies. Different students may solve the same mathematical problem using numerical, graphical, visual, or algebraic approaches. Comparing these strategies creates opportunities to examine the relationships among different mathematical representations and evaluate the efficiency and generalizability of each approach. Such discussions can deepen conceptual understanding because students are encouraged to recognize mathematics as a connected system rather than a collection of isolated procedures.Communication and mathematical discourse constitute another essential pedagogical process. Inquiry is not exclusively an individual cognitive activity but can also develop through social interaction. When students explain their ideas, listen to alternative strategies, question assumptions, and respond to arguments, they are required to clarify and refine their mathematical thinking. Collaborative discourse can therefore function as a mechanism for conceptual development. Students may initially hold incomplete or informal understandings, but interaction with peers and teachers can support the gradual refinement of these ideas into more formal mathematical reasoning. The teacher plays a particularly important role in establishing productive mathematical discourse. Inquiry-oriented classrooms require more than simply asking students to work in groups. Teachers need to create norms in which mathematical ideas can be questioned and errors can be treated as opportunities for learning. Rather than immediately evaluating every response as correct or incorrect, teachers can encourage students to explain their reasoning and invite others to examine the validity of an argument. Such practices shift classroom attention from answer-oriented learning toward reasoning-oriented learning. Recent studies on inquiry-based pedagogies have emphasized the importance of teacher professional competence in managing these processes. Teachers need to understand when to intervene, when to allow productive struggle, and how to provide guidance without removing students' intellectual responsibility (Professional Learning Interventions for Inquiry-Based Pedagogies in Primary Classrooms, 2025). This issue is particularly relevant in mathematics because students may require assistance in connecting informal strategies with formal mathematical concepts. The teacher must therefore act as a facilitator who monitors emerging ideas and supports conceptual development through purposeful intervention. Another characteristic of mathematical inquiry is the process generalization. Mathematical learning should not remain limited to solving individual problems. Through inquiry, students should gradually move from specific examples toward broader mathematical relationships. For instance, students may investigate several numerical cases and identify a recurring pattern. The next intellectual challenge is determining whether the pattern can be generalized and expressed as a mathematical rule. Generalization requires students to recognize structures that extend beyond particular examples and is therefore central to the development of abstract mathematical thinking. The transition from particular examples to general principles represents one of the most significant pedagogical contributions of inquiry-based mathematics learning. Students often begin with concrete experiences or specific numerical cases because these provide accessible entry points for exploration. Through systematic investigation, comparison, and reasoning, they can gradually identify invariant relationships. Teachers can then support students in formalizing these relationships through appropriate mathematical language and symbolic notation. In this way, formal mathematical knowledge emerges as a means of expressing and communicating relationships that students have previously investigated. Reflection is the final process that connects individual inquiry experiences with broader mathematical understanding. After completing an investigation, students need opportunities to reconsider what they have learned, evaluate the effectiveness of their strategies, and identify mathematical principles that can be applied to other situations. Reflection enables learners to move beyond task completion toward conceptual consolidation. Without reflection, students may successfully complete an inquiry activity without recognizing the general mathematical ideas embedded within their exploration. The pedagogical processes described above demonstrate that inquiry-based mathematics learning is inherently cyclical. Students may move repeatedly between questioning, exploration, representation, conjecturing, reasoning, communication, and reflection. These processes should not necessarily be understood as a rigid linear sequence. For example, a student may develop an initial conjecture, discover contradictory evidence, revise the conjecture,

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and conduct further investigation. Such iterative processes reflect the nature of authentic mathematical thinking, where understanding frequently develops through revision and refinement. Based on this perspective, mathematical inquiry can be conceptualized as an interconnected process consisting of several key intellectual activities: problem questioning, exploration, representation, conjecturing, investigation, reasoning, justification, communication, generalization, and reflection. Each process contributes a different function to the development of mathematical understanding. Questioning initiates intellectual engagement; exploration generates experiences and observations; representations make relationships visible; conjecturing provides tentative explanations; investigation tests ideas; reasoning and justification establish mathematical validity; communication enables ideas to be examined collectively; generalization extends understanding beyond particular cases; and reflection integrates new knowledge into broader conceptual structures.The integration of these processes explains why inquiry-based learning has considerable potential for promoting meaningful mathematics learning. Students do not simply receive mathematical concepts in their final form. Instead, they participate in intellectual processes through which mathematical relationships are explored and progressively formalized. Nevertheless, the success of this process depends on careful pedagogical design. Inquiry tasks must be mathematically meaningful, teacher guidance must be responsive rather than controlling, and students must be provided with sufficient opportunities to communicate and reflect upon their ideas. Therefore, inquiry-based learning in mathematics should be viewed as a structured form of intellectual engagement rather than unrestricted discovery. Its central objective is to create a learning environment in which students can experience the processes of mathematical thinking while receiving sufficient support to transform exploration into conceptual understanding. The next section discusses how these characteristics can be translated into systematic pedagogical phases for classroom implementation.

Pedagogical Phases of Inquiry-Based Mathematics Learning

The implementation of inquiry-based learning in mathematics requires a structured pedagogical process that guides students from initial curiosity toward conceptual understanding. Although inquiry is often described as an iterative process, several interconnected phases can facilitate its practical implementation in mathematics classrooms. The first phase is orientation and problem identification, in which teachers present meaningful mathematical situations that stimulate curiosity and intellectual engagement. Problems should encourage students to explore relationships rather than immediately apply familiar algorithms. The teacher's role at this stage is to establish a productive learning environment and activate students' prior knowledge. The second phase involves questioning and conjecturing. Students identify mathematical relationships, formulate questions, and develop tentative explanations or conjectures. Rather than immediately evaluating whether students' ideas are correct, teachers should encourage learners to explain the basis of their thinking and consider alternative possibilities. The third phase is mathematical investigation. Students explore the problem through strategies such as generating examples, constructing diagrams, organizing data, comparing representations, or using mathematical tools. This phase allows students to test conjectures and identify patterns through active engagement. The fourth phase involves reasoning and justification. Students analyze the results of their investigations and develop arguments to explain why particular mathematical relationships occur. This stage is essential because inquiry should move beyond empirical observation toward logical reasoning and mathematical justification. The fifth phase is communication and reflection. Students communicate their strategies and conclusions, compare alternative solutions, and reflect on the mathematical ideas developed during the investigation. Through teacher-facilitated discussion, informal discoveries can gradually be connected with formal mathematical concepts. Reflection also helps students recognize how newly acquired knowledge relates to their previous understanding. These phases should not be interpreted as a rigid linear procedure. Mathematical inquiry is frequently iterative, allowing students to revise conjectures, reconsider strategies, and conduct additional investigations when new evidence emerges. Effective implementation therefore requires teachers to balance structured guidance with opportunities for student autonomy. Recent research on inquiry pedagogy emphasizes that such guidance is necessary to ensure that exploration develops into meaningful conceptual understanding rather than unstructured activity (Lazonder & Harmsen, 2016; Koskinen & Pitkäniemi, 2022).

Inquiry as a Pathway toward Meaningful Mathematical Learning

Inquiry-based learning can promote meaningful mathematical learning when students are actively involved in constructing connections between new mathematical experiences and their existing knowledge. The central mechanism is not simply the completion of inquiry activities but the cognitive processes that occur while students investigate, represent, reason about, and reflect on mathematical relationships. Meaningful learning is therefore more likely to emerge when inquiry is deliberately designed to connect exploration with conceptual understanding (Koskinen & Pitkäniemi, 2022). The first mechanism is activation of prior knowledge. Inquiry problems provide opportunities for students to recall and use previously learned concepts in unfamiliar situations. When students attempt to explain a new mathematical phenomenon using existing knowledge, they may recognize both the usefulness and limitations of their current understanding. This process creates opportunities for conceptual restructuring and deeper learning. Contextualized and socially supported mathematics learning has been shown to facilitate such connections between prior knowledge and new mathematical ideas (Koskinen & Pitkäniemi, 2022). The second mechanism is mathematical exploration and representation. Students investigate problems by using numerical examples, diagrams, tables, graphs, manipulatives, or symbolic expressions. Multiple representations allow learners to examine mathematical relationships from different perspectives and make abstract structures more visible. When students move between representations, they are required to identify the underlying relationships that remain invariant across different forms. This process can strengthen conceptual understanding rather than limiting learning to symbolic manipulation. The third mechanism is reasoning and justification. Inquiry requires students to explain why their observations or conjectures are valid. Instead of accepting a mathematical result simply because it produces a correct answer, students are encouraged to provide evidence, construct arguments, and examine possible exceptions. Such activities promote deeper engagement with mathematical structures and support the development of reasoning abilities. Recent research on inquiry-oriented mathematics learning emphasizes the importance of explanation and justification as components of higher-order mathematical thinking. The fourth mechanism is

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mathematical discourse and social negotiation of meaning. When students communicate their strategies and compare their reasoning with those of peers, they encounter alternative ways of interpreting mathematical situations. Discussion can reveal misconceptions, expose different representations, and encourage students to reconsider their assumptions. Meaning is consequently developed not only through individual cognitive activity but also through interaction and communication. This is consistent with research emphasizing the importance of social interaction and communication in meaningful mathematics learning (Koskinen & Pitkäniemi, 2022). The fifth mechanism is reflection and conceptual integration. Inquiry experiences become meaningful when students are given opportunities to reflect on what they discovered and connect their findings with broader mathematical principles. Reflection allows learners to move from particular examples toward general concepts and to recognize how new knowledge relates to previous understanding. Without this stage, inquiry may remain an engaging activity without producing durable conceptual learning. An important implication is that inquiry should involve a gradual movement from concrete exploration to mathematical abstraction. Students may begin with examples, contexts, or visual representations, but effective inquiry ultimately requires them to identify mathematical structures and express them using appropriate formal language. This movement can help students understand mathematical formulas and procedures as representations of relationships that they have investigated rather than as arbitrary rules imposed by the teacher. From this perspective, the effectiveness of inquiry depends on three interconnected conditions: the quality of the mathematical task, the quality of teacher scaffolding, and the depth of student reflection. A poorly designed task may generate activity without meaningful mathematical thinking; insufficient scaffolding may result in confusion; and limited reflection may prevent students from integrating their discoveries into coherent conceptual structures. Inquiry-based mathematics learning should therefore be designed as a carefully supported process in which exploration and conceptual formalization are deliberately connected. Ultimately, inquiry contributes to meaningful mathematics learning when students are able to answer not only *"What is the answer?"* but also *"How did we obtain it?", "Why does it work?", and "Can this relationship be generalized?"* These questions represent a shift from procedural performance toward mathematical understanding. Inquiry consequently provides a pedagogical pathway through which students can develop mathematics as connected knowledge characterized by relationships, reasoning, and meaningful application.

CONSLUSION

Inquiry-Based Learning (IBL) provides a meaningful pedagogical pathway for transforming mathematics learning from procedural transmission toward active construction of mathematical understanding. Through questioning, exploration, conjecturing, representation, reasoning, justification, communication, and reflection, students are provided with opportunities to connect prior knowledge with new mathematical ideas and to develop deeper conceptual understanding. The discussion indicates that meaningful mathematical learning does not emerge from exploration alone. The effectiveness of inquiry depends on the quality of mathematical tasks, opportunities for mathematical discourse, students' engagement, and appropriate instructional scaffolding. In this context, the teacher plays a critical role in designing inquiry situations, asking productive questions, monitoring students' reasoning, and gradually reducing support as students become more independent (Koskinen & Pitkäniemi, 2022; Saputra et al., 2024). Therefore, inquiry-based mathematics learning should be understood as a guided process that balances student autonomy and teacher support, rather than as unguided discovery. When appropriately designed, inquiry can connect mathematical exploration with conceptual understanding, reasoning, communication, and problem solving. This perspective has implications for mathematics teachers and curriculum designers in developing learning environments that prioritize meaningful mathematical thinking rather than merely the reproduction of procedures. Future research should examine how different forms of inquiry, scaffolding, digital tools, and teacher professional development influence students' mathematical learning across diverse educational contexts. Such research can further clarify the conditions under which inquiry-based mathematics learning produces sustainable improvements in meaningful understanding and higher-order mathematical thinking.

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