*26 (1), 2025, 268-279*

**Jurnal Pendidikan MIPA**

e-ISSN: 2685-5488 | p-ISSN: 1411-2531

http://jurnal.fkip.unila.ac.id/index.php/jpmipa/

# The Effectiveness of Discovery, Inquiry, Problem, and Project-Based Learning in Mathematics Education: A Systematic Literature Review

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**Abstract:** Discovery-based learning plays a crucial role in enhancing students' mathematical understanding and critical thinking skills. This study analyzes the implementation of four major models Discovery Learning, Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), and Project-Based Learning (PjBL) through a Systematic Literature Review (SLR) of 52 Scopus-indexed studies. The findings indicate that these models effectively improve conceptual understanding, higher-order thinking skills, and student motivation. Data from TIMSS (Trends in International Mathematics and Science Study) 2019 and PISA (Programme for International Student Assessment) 2022 confirm that countries consistently implementing these models demonstrate superior mathematical performance. The integration of technology, such as GeoGebra and e-learning platforms, further enriches learning experiences and enhances instructional effectiveness. However, challenges remain, including time constraints, uneven understanding of implementation, and difficulties in assessment design. This study reaffirms that discovery-based learning is an appropriate approach for 21st-century mathematics education. Recommendations include increasing research at the primary and secondary education levels, exploring artificial intelligence-based learning technologies, and developing more effective assessment strategies to support the implementation of this model across diverse educational contexts.

**Keywords:** discovery-based learning, mathematics education, systematic literature review.

## ▪ INTRODUCTION

Mathematics education is crucial in developing students’ logical, systematic, and critical thinking abilities in the modern era. The global transformation in education, accelerated by technological developments and 21st-century competency demands, presents significant challenges in mathematics learning. The paradigm shifts from teacher-centered to student-centered learning have driven the evolution of more adaptive and effective learning methods to develop students’ mathematical competencies (Treve, 2024). The constructivist paradigm in education presents a fundamental perspective on the teaching and learning process that emphasizes students’ active role in building knowledge (Piaget in Slamet & Widodo, 2024). The basic concept of constructivism underlines that knowledge cannot simply be transferred from educators to students but rather an active process where students independently construct understanding through experience and interaction with their environment (Suryana et al., 2022). Vygotsky emphasizes the role of social interaction in knowledge formation, introducing the concept of the “zone of proximal development,” which underlines the importance of guidance and scaffolding in the learning process (Vygotsky in Shabani et al., 2010).

Discovery-based learning models serve as a broad umbrella encompassing various learning approaches emphasizing students’ discovery process and knowledge construction. Bruner (1984), as one of the pioneers in discovery learning theory, affirms that meaningful learning occurs when students actively discover principles and conceptual relationships. The main characteristic of discovery-based learning models is

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DOI: http://dx.doi.org/10.23960/jpmipa/v26i1.pp268-279
Received: 27 February 2025
Accepted: 10 March 2025
Published: 14 April 2025

their emphasis on investigation, exploration, and construction of understanding by students, with teachers acting as facilitators and guides (Ozdem-Yilmaz & Bilican, 2020).

Discovery Learning, one of the discovery-based learning models, was developed based on Piaget's constructivism theory and Bruner's discovery theory. This model emphasizes discovering previously unknown concepts or principles through structured stages. In their meta-analysis, Khairunnisa & Juandi (2022) demonstrate that Discovery Learning is efficacious in improving conceptual understanding and higher-order thinking skills in mathematics. Research by Saputri et al (2023) shows that this model creates a learning environment that encourages students to analyze problems and develop solutions independently.

Inquiry-Based Learning (IBL) falls under the category of discovery-based learning models as it places systematic investigation at the core of learning. The National Research Council in Teig (2022) defines IBL as a learning approach that involves students in scientific inquiry processes to build understanding. This model shares characteristics with discovery-based learning: orientation, conceptualization, investigation, conclusion, and discussion. Through their longitudinal study, Laursen et al (2011) prove that IBL is effective in developing mathematical reasoning abilities and positive attitudes toward mathematics.

Problem-Based Learning (PBL) is a discovery-based learning model that uses authentic problems to trigger knowledge discovery and construction. Bagus et al. (2023) Bagus et al (2023) explain that PBL integrates discovery-based learning principles through learning stages, including problem orientation, organization, investigation, development, analysis, and evaluation. Research conducted by Surya et al (2018)shows that PBL effectively improves mathematical problem-solving abilities and self-regulated learning.

Project Based Learning (PjBL) is a discovery-based learning model that integrates the discovery process through comprehensive project work. Anteplioğlu (2019) identifies five PjBL criteria that align with discovery-based learning: centrality, driving question, constructive investigation, autonomy, and realism. This model encourages students to discover and construct knowledge through authentic and meaningful project experiences. A study by Susanto et al (2020) proves the effectiveness of PjBL in developing problem-solving abilities and mathematical critical thinking skills.

The role of teachers in discovery-based learning has transformed from information providers to learning facilitators. Yuniarti emphasizes that the effectiveness of developing problem-solving abilities heavily depends on the quality of presented problem situations and teacher-provided scaffolding. Yuniarti & Suksetiyarno (2020) assert that educators must develop the ability to design challenging learning experiences, encourage critical questions, and provide adequate cognitive support. In developing mathematical problem-solving skills, Polya's research, as cited in Snyder & Snyder (2008), reveals the importance of giving students opportunities to explore and construct their understanding. These four learning models share characteristics that align with discovery-based learning principles proposed by Bruner (1961) and developed by subsequent researchers. First, all models position students as the center of learning and active knowledge constructors. Second, the learning process emphasizes discovery and understanding construction through direct experience. Third, teachers act as facilitators guiding the discovery process. Fourth, learning is designed to develop higher-order thinking skills and 21stcentury competencies (Sundari & Fauziati, 2021). Although various studies have shown the effectiveness of discovery-based learning models, their implementation in mathematics education still faces multiple challenges. A survey by Wahyudi et al (2018) identified several main obstacles: time constraints, lack of understanding about model implementation, difficulties in designing appropriate learning activities, and challenges in assessing learning processes and outcomes. Fitri et al (2020) emphasize that traditional instructive and linear knowledge transfer learning models are less effective in developing students' critical thinking abilities, creativity, and learning independence.

Data from TIMSS (Trends in International Mathematics and Science Study) 2019 and PISA (Programme for International Student Assessment) 2022 show that countries consistently implementing discovery-based learning models in mathematics tend to perform better. Singapore ranks top in both assessments and has integrated discovery-based learning models into its mathematics curriculum since 2012. A comparative study by Anđelković & Maričić (2023) reveals a positive correlation between the implementation of discovery-based learning models and students' mathematical achievement at the international level. The development of digital technology opens new opportunities for implementing discovery-based learning models. Integrating dynamic geometry software, computer algebra, and learning management systems can enrich learning experiences and facilitate more effective discovery processes. Behzadan & Kamat (2013) found that using technology in discovery-based learning significantly increases student engagement and conceptual understanding. In Indonesia, the implementation of discovery-based learning models gained new momentum with the enactment of the Merdeka Curriculum. The learning paradigm emphasizing competency and character development aligns with discovery-based learning principles. A study conducted by Fitriyadi (2013) across 156 schools in Indonesia shows increased adoption of discovery-based learning models, although implementation levels vary across schools and regions.

The significance of research or development of constructivism-based learning models lies in their potential to transform the educational paradigm. By providing appropriate space and facilitation, students receive information and actively engage in discovering, processing, and reconstructing knowledge according to their contexts and experiences. This reinforces that knowledge gained through self-discovery proves to have more significant depth and meaning than merely passively received knowledge. Implementing discovery-based learning models in mathematics education requires in-depth study through a systematic literature review.

Based on the preceding discourse, this investigation delineates several pivotal issues pertinent to the execution of discovery-based learning frameworks within the realm of mathematics education. While an array of empirical studies has substantiated the efficacy of these models in augmenting students' critical thinking, problem-solving capabilities, and conceptual comprehension, persistent challenges endure in their deployment across diverse educational environments. Consequently, the research inquiries posited in this investigation are articulated as follows:

1. What extent do discovery-based learning models (namely Discovery Learning, Inquiry-Based Learning, Problem-Based Learning, and Project-Based Learning)

contribute to the enhancement of various dimensions of students' mathematical competencies?
2. What determinants play a crucial role in the successful operationalization of discovery-based learning frameworks in mathematics education?
3. In what ways can the incorporation of information and communication technology facilitate the implementation of discovery-based learning models to augment the efficacy of mathematical instruction?

In light of the aforementioned research inquiries, this study aspires to:

1. Examine the efficacy of discovery-based learning models in fostering students' mathematical competencies through a methodical review of the existing literature.
2. Identify the challenges and impediments encountered during the implementation of discovery-based learning frameworks and propose strategies that may be employed to surmount these barriers.
3. Elucidate various modalities of technology integration within discovery-based learning and assess their influence on students' mathematics learning outcomes.

Through a comprehensive literature review, this investigation is projected to yield profound insights into the application of discovery-based learning models in mathematics education, as well as the role of technology in bolstering their effectiveness. The outcomes of this study are expected to serve as a valuable reference for educators, researchers, and policymakers in the formulation of more adaptive and innovative pedagogical strategies aimed at enhancing the quality of mathematics education in the digital age.

## ▪ METHOD

This research utilizes the Systematic Literature Review (SLR) methodology to systematically identify, assess, and synthesize conclusions from empirical evidence pertinent to discovery-based learning models within the domain of mathematics education. SLR represents a rigorous approach for the systematic collection, critical evaluation, integration, and presentation of findings derived from diverse studies that correspond to specific research inquiries or topics of scholarly interest (Pati & Lorusso, 2018). This SLR adheres to the guidelines outlined in the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) protocol, which encompasses four principal phases: identification, screening, eligibility assessment, and integration (Moher et al., 2010; Juandi & Tamur, 2020).

The systematic review of the literature was executed utilizing the Scopus database, incorporating defined search terms: Mathematics Education, Discovery Learning, Inquiry-Based Learning, Problem-Based Learning and Project-Based Learning. The retrieval process was conducted through the application of a combination of Boolean operators (AND, OR) alongside wildcard symbols (*, ?) to guarantee an extensive scope of results. The data was retrieved on November 31, 2024, culminating in a total of 4,138 scholarly articles.

To ensure alignment with the research objectives, the selection process was conducted utilizing the following criteria:

*Inclusion Criteria:*
1. Scholarly articles in the format of journal publications and conference proceedings.

2. Publications released within the temporal framework of 2014–2024.
3. Documents authored in the English language.
4. Open access publications to guarantee accessibility.
5. Articles that directly engage with the learning models under investigation.

*Exclusion Criteria:*
1. Publications in languages other than English.
2. Documents in the form of review articles, book chapters, or editorials.
3. Publications that are not accessible through open access.
4. Articles that do not pertain to the research topic.

The selection process culminated in the identification of 52 articles that satisfied the criteria for subsequent analysis. The selected articles underwent an exhaustive examination employing the Thematic Analysis methodology, which encompasses several fundamental stages:

1. Data Familiarization: The selected articles were meticulously reviewed to gain a comprehensive understanding of their content and the contextual backdrop of the research.
2. Coding: Crucial concepts within each article were discerned and annotated utilizing software applications such as NVivo
3. Categorization: The discerned codes were systematically organized into various categories predicated on recurring themes observed throughout the articles.
4. Theme Identification: From the established categories, principal themes pertinent to discovery-based learning models were recognized and systematically arranged.
5. Synthesis and Interpretation: The recognized themes were subjected to further analysis to elucidate research patterns, distinctions, and the implications arising from the findings.

Furthermore, the evaluation of article quality was executed employing the Joanna Briggs Institute Critical Appraisal Checklist, which encompasses methodological validity, relevance of research outcomes, and contributions to the academic domain. The results derived from this analysis served to formulate a comprehensive conclusion regarding the efficacy and research trajectories of discovery-based learning models. The process of selecting literature is depicted in the subsequent PRISMA flowchart:

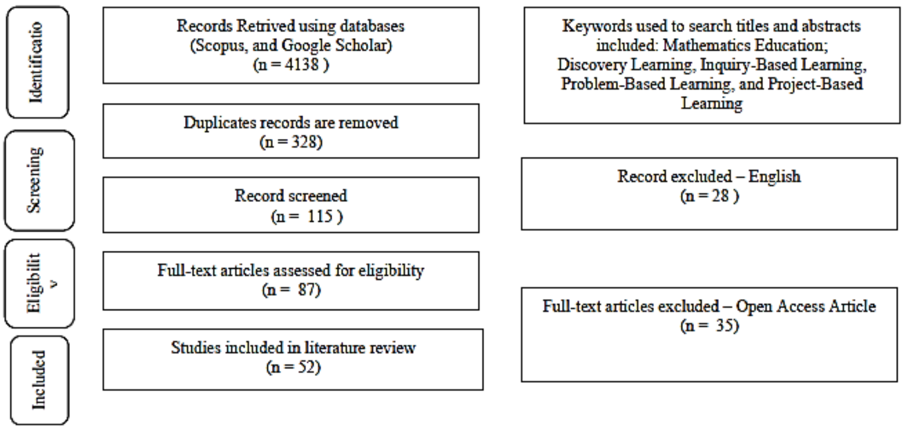


**Figure 1.** Prism flow chart

By following this methodology, this study ensures that the data used is relevant, high-quality, and can systematically address the research questions.

## ▪ RESULT AND DISSCUSSION

In order to comprehend the research trajectories associated with discovery-oriented learning frameworks within the domain of mathematics education, we conducted a comprehensive analysis of numerous scholarly articles, taking into account various attributes including the year of publication, the methodological design employed, the educational tier, the learning models examined, and the variables assessed. Table 1 provides a concise overview of the characteristics of the studies that were subjected to analysis:

**Table 1.** Characteristics of analyzed article

| Education Level | Research Design | Learning Model | Measured Variables |
|---|---|---|---|
| Higher Education | Quantitative (48%) | Discovery Learning | Critical Thinking Skills, Learning Motivation |
| Senior High School | Qualitative (25%) | IBL, PBL | Problem Solving, Collaborative Skills |
| Junior High School | Mixed Methods (8%) | PjBL | Conceptual Understanding, Creative |
| Elementary School | RnD (11%) | Discover Learning | Creative Thinking Skills |

The analysis of the distribution of educational attainment reveals a preeminence of scholarly investigation at the tertiary education tier (50%), succeeded by senior secondary education (20%), junior secondary education (17%), and elementary education (13%). This finding underscores the necessity for augmented scholarly inquiry within the primary and secondary educational sectors. Additional visual representations are provided in Figures 1 and 2 to elucidate the distribution of data according to educational attainment and the geographic context of the research.

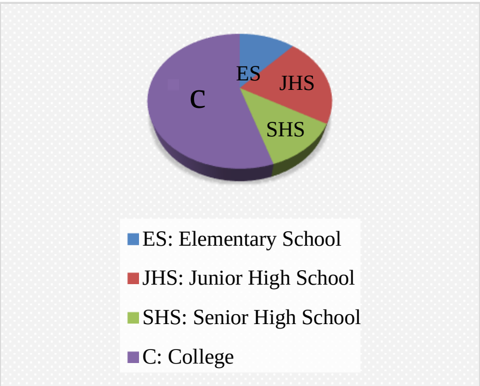


**Figure 1.** Primary study data by education level

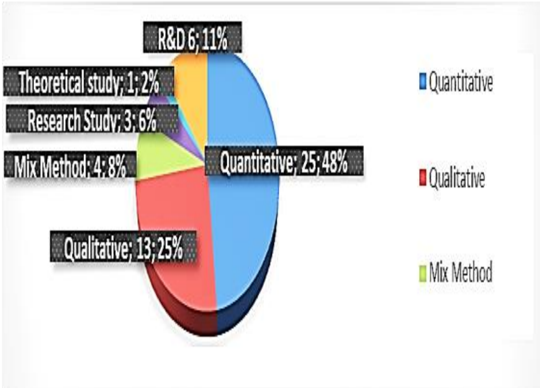


**Figure 2.** Demographic of primary study data based on location of research subjects

**The Impact of Discovery-Based Learning Models on Students' Mathematical Proficiencies**

Discovery-based learning paradigms, which include Discovery Learning, Inquiry-Based Learning, Problem-Based Learning, and Project-Based Learning, have been empirically substantiated to enhance various dimensions of students' mathematical competencies. Discovery Learning, as articulated by Muchlis et al (2021), facilitates the advancement of critical thinking and problem-solving skills through independent exploration of concepts. Nurhayani et al (2020) demonstrated that structured Discovery Learning significantly elevates students' motivation to engage in learning. Inquiry-Based Learning (IBL) assumes a crucial function in strengthening conceptual understanding and competencies related to mathematical interconnections (Handayani et al., 2019) while simultaneously enhancing students' motivation for academic pursuits (Gómez-Chacón et al., 2023). In a complementary fashion, Problem-Based Learning (PBL) fosters the development of critical thinking and collaborative abilities requisite for tackling complex mathematical problems (Susilo et al., 2018), whereas Project-Based Learning (PjBL) emphasizes the integration of theoretical constructs into practical real-world initiatives, thereby augmenting students' mathematical communication proficiencies, as noted byFitriani & Rohman (2021). These observations are consistent with constructivist educational theories, including Piaget's cognitive developmental theory and Vygotsky's social constructivism, which stress the importance of active engagement and scaffolding within the learning process. Furthermore, when juxtaposed with systematic literature reviews (SLR) on analogous subjects, these findings predominantly validate prior research affirming the beneficial impacts of discovery-based models, although variations in certain studies indicate that contextual factors such as educator expertise, student preparedness, and institutional support significantly influence educational outcomes.

**Key Determinants for the Successful Implementation of Discovery-Based Learning**

The successful implementation of discovery-based learning paradigms is dependent upon several critical factors. A primary determinant is the readiness of educators to effectively administer these pedagogical models. Kalogeropoulos et al (2021) emphasize the importance of professional development for educators to skillfully facilitate discovery-based learning endeavors. Another crucial factor is the availability of adequate resources and infrastructural support, which includes appropriate instructional materials and an educational milieu conducive to student inquiry (Wardono et al., 2018). Furthermore, the active participation of students is essential, as discovery-based learning frameworks demand considerable engagement in the exploration of concepts and the resolution of problems (Kurani & Syarifuddin, 2020). In addition, a flexible curriculum is vital for promoting the effective implementation of these models, particularly by allowing sufficient time for students to investigate and reflect upon the concepts they encounter (Pratiwi & Simangunsong, 2021). The implications of these findings for pedagogical practice indicate that educators should utilize structured scaffolding techniques to direct student inquiry while promoting autonomy in learning. Educational institutions must also ensure that adequate resources and time allocations are available to support effective implementation. Nevertheless, the limitations regarding the representativeness of the reviewed articles must be recognized, as publication bias may influence the generalizability of the findings. Subsequent research should therefore investigate the efficacy of discovery-based learning in diverse educational contexts, particularly in schools with limited resources.

**The Role of Technology in Enhancing the Effectiveness of Discovery-Based Learning Models**

The integration of technological instruments within discovery-oriented learning frameworks has been demonstrated to enhance their effectiveness within the domain of mathematics education. Marion et al (2023) demonstrated that the utilization of software applications such as GeoGebra in Discovery Learning significantly improves students' analytical reasoning capabilities. The implementation of technology-enhanced learning environments, exemplified by platforms such as Google Classroom and Seesaw within Inquiry-Based Learning (IBL), as articulated by Kalogeropoulos et al (2021), promotes enhanced interaction and self-directed exploration among learners. Furthermore, technology considerably amplifies the efficacy of Project-Based Learning (PBL) in fostering mathematical problem-solving competencies by providing access to digital resources and interactive simulations (Yaniawati et al., 2019). Within the Project-based Learning (PjBL) framework, the application of digital platforms like Madrasati has been shown to accelerate students' understanding of mathematical concepts by nurturing a more dynamic and project-centric educational environment (Alenezi, 2023). These findings reinforce cognitive learning theories, such as Sweller's cognitive load theory, which asserts that technology can alleviate extraneous cognitive load and enhance problem-solving efficiency. In juxtaposing these findings with previous research, disparities in technological infrastructure and accessibility emerge as pivotal factors influencing the efficacy of technology-enhanced discovery-based learning. Future investigations could concentrate on conducting meta-analyses to quantify the cumulative impact of discovery-based models, scrutinizing their effectiveness across varied educational settings, and exploring the influence of contextual elements on their implementation. Such inquiries would yield a more holistic understanding of how to optimize discovery-based learning for a heterogeneous population of learners and learning environments.

In conclusion, discovery-based learning models assume a crucial role in the enhancement of students' mathematical proficiencies, with their effectiveness being contingent upon variables such as educator readiness, resource availability, and a curriculum supportive of conceptual exploration. The further incorporation of technology possesses the potential to strengthen the execution of these models, thereby rendering them more effective and adaptable to a variety of educational contexts. Hence, it is prudent that forthcoming research endeavors investigate the synergistic relationship between discovery-based learning models and technology to cultivate the development of more innovative and efficacious mathematics learning experiences.

## ▪ CONCLUSION

The application of discovery-oriented pedagogy within the domain of mathematics education, substantiated by empirical evidence derived from 52 scholarly articles, has demonstrated a substantial impact on the enhancement of students' competencies, which encompass conceptual comprehension, critical analytical skills, problem-solving capabilities, and intrinsic motivation for learning. Educational frameworks such as

Discovery Learning, Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), and Project-Based Learning (PjBL) facilitate substantial learning experiences by prioritizing active inquiry and fostering student participation within the educational process. The efficacy of these pedagogical models is contingent upon educators' preparedness to devise suitable learning experiences, the provision of sufficient resources, and a curriculum that is adaptable, thereby allowing for comprehensive exploration of subject matter. Furthermore, the incorporation of technology into discovery-based learning methodologies has been demonstrated to augment the efficacy of the educational experience through the provision of access to interactive simulations, digital instructional tools, and technology-enhanced learning environments. Nonetheless, challenges such as temporal limitations, educators' insufficient grasp of effective implementation strategies for these models, and complexities associated with the evaluation of learning outcomes persist as formidable barriers that warrant thorough examination and resolution.

## ▪ RECOMMENDATION

Future investigations ought to seek to rectify current deficiencies and augment the execution of discovery-based pedagogical frameworks. Numerous pivotal domains necessitate further exploration to optimize their efficacy across a variety of educational contexts. The subsequent recommendations underscore prospective research trajectories:

a. Conduct comprehensive meta-analyses to quantitatively assess the efficacy of discovery-based learning frameworks.
b. Examine contextual variables that affect the successful execution of discovery-based learning, including institutional regulations, socio-economic circumstances, and the dynamics between educators and learners.
c. Investigate emerging technological innovations, such as artificial intelligence and virtual reality, to enhance the efficacy of discovery-based learning within the domain of mathematics education.
d. Compare diverse discovery-based learning methodologies across various educational levels, student proficiency tiers, and cultural paradigms.
e. Formulate more structured professional development programs for educators to guarantee the effective application of discovery-based learning frameworks.
f. Devise a more flexible curriculum along with appropriate assessment strategies to facilitate discovery-based learning.

## ▪ ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation and gratitude to Lembaga Pengelola Dana Pendidikan (LPDP), Ministry of Finance of The Republic of Indonesia, for its valuable support in facilitating this publication and fostering collaboration

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