Science Education Through the Predict – Investigation – Collaboration – Technology Application (PICOTA) Framework : A Systematic Review

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Abstract. The Predict–Observe–Explain (POE) model has been widely implemented in primary science education to support conceptual change and the development of science process skills. However, research on POE continues to exhibit conceptual fragmentation, reflected in the diversity of theoretical foundations, instructional designs, and learning outcome orientations. Furthermore, the conventional POE model has not fully accommodated the demands of twenty-first-century learning, which emphasize collaboration and the integration of technology. Therefore, this study aims to examine the theoretical foundations, instructional designs, and learning outcomes associated with POE, while reconceptualizing the model within the context of primary science education. This study employed a Systematic Literature Review (SLR) based on the PRISMA 2020 guidelines. Articles were retrieved from the Scopus, Web of Science (WoS), and ERIC databases, covering publications from 2010 to 2025. A total of 78 articles that met the inclusion criteria were analyzed using a thematic synthesis approach. The findings reveal that constructivism, conceptual change theory, inquiry learning, and social constructivism constitute the dominant theoretical foundations underpinning POE research. The implementation of POE has evolved toward investigation-based, collaborative, and technology-enhanced learning approaches. The review also indicates consistent positive effects on conceptual understanding, science process skills, critical thinking, communication, and collaboration. Based on these findings, this study proposes the PICOTA (Predict–Investigation–Collaboration–Technology Application) conceptual framework as a more relevant science learning model for addressing the needs of twenty-first-century education.

Keywords: predict–observe–explain, PICOTA, primary science education, systematic literature review, twenty-first-century learning.

INTRODUCTION

The rapid transformation of science, technology, and society in the twenty-first century has fundamentally reshaped the goals of science education worldwide. Contemporary science education is expected not only to develop students' conceptual understanding of scientific phenomena but also to cultivate scientific literacy, critical thinking, collaboration, creativity, communication, and digital competence (Thornhill-miller et al., 2025; Voogt & Roblin, 2012). These competencies are increasingly recognized as essential for preparing learners to participate effectively in a knowledge-based society characterized by complex scientific and technological challenges. Consequently, educational systems across many countries have shifted their focus from teacher-centered knowledge transmission toward student-centered approaches that promote active inquiry, collaborative problem-solving, and meaningful use of technology (Bybee & McCrae, 2011; Kwok, 2016).

Within primary science education, this transformation presents a particularly important challenge. Primary school students are at a critical stage of cognitive development where scientific concepts are often constructed from everyday experiences that may not always align with scientific explanations (Korur et al., 2025). As a result, misconceptions and alternative conceptions frequently emerge and can persist unless instructional interventions effectively facilitate conceptual restructuring (Vosniadou, 2019). For this reason, science educators have increasingly emphasized instructional approaches grounded in constructivist learning theory, which views learning as an active process of knowledge construction rather than passive information acquisition (Taber, 2024). Among the constructivist approaches developed to address conceptual change in science learning, the Predict–Observe–Explain (POE) model has become one of the most widely implemented and researched instructional strategies.

The POE model was initially introduced by

White and Gunstone (1992) as a pedagogical strategy designed to reveal learners' prior conceptions and facilitate conceptual change through cognitive conflict. The model consists of three sequential stages. In the prediction phase, students are encouraged to predict the outcomes of a phenomenon and justify their reasoning. During the observation phase, learners observe an experiment, demonstration, or scientific event. Finally, in the explanation phase, students reconcile discrepancies between their predictions and observations through reflection and discussion. This instructional sequence allows learners to confront inconsistencies in their thinking and reconstruct their understanding based on scientific evidence (Hsu & Tsai, 2011).

Over the past three decades, POE has been extensively applied across various science disciplines, including physics, chemistry, biology, and environmental science. Research consistently demonstrates that POE contributes significantly to conceptual understanding by helping learners identify and overcome misconceptions (Bariş, 2022; Hsiao et al., 2017). Studies conducted in primary and secondary science education have shown that POE enhances students' understanding of abstract scientific concepts by encouraging active engagement with evidence-based reasoning (Chun & Hsuan, 2023). The model has also been found to improve students' retention of scientific concepts, suggesting that conceptual change achieved through POE may be more enduring than learning acquired through traditional instruction (Özcan & Uyanık, 2022).

Beyond conceptual understanding, recent studies indicate that the impact of POE extends to a broader range of cognitive and affective learning outcomes. Empirical evidence suggests that POE promotes science process skills, scientific reasoning, critical thinking, metacognitive awareness, and problem-solving abilities (Trisnayanti et al., 2023). Through the prediction process, students engage in hypothesis generation and reasoning. Observation activities encourage systematic data collection and evidence evaluation, while explanation tasks foster reflection and argumentation. Consequently, POE has increasingly been recognized as a powerful instructional model capable of supporting inquiry-oriented science learning.

The growing popularity of POE is reflected in the substantial increase in related research published during the last decade. A review of the literature reveals that POE has been implemented in diverse educational contexts and integrated with various instructional innovations, including laboratory-based inquiry, problem-based learning, STEM education, digital simulations, virtual laboratories, augmented reality environments, and blended learning approaches (Hwang et al., 2022). These developments indicate that POE is no longer viewed solely as a conceptual change strategy but has evolved into a flexible instructional framework adaptable to contemporary science learning environments.

At the same time, the theoretical foundations underpinning POE have expanded considerably. Early studies predominantly framed POE within conceptual change theory and cognitive constructivism. However, more recent investigations have increasingly drawn upon inquiry-based learning, social constructivism, metacognition, collaborative learning, and sociocultural perspectives (Karakoc et al., 2025). This theoretical diversification reflects broader developments in science education research, where learning is increasingly understood as both an individual cognitive process and a socially mediated activity involving interaction, communication, and shared meaning-making (Hausfather, 2012).

Despite the extensive body of research supporting POE, several important challenges remain unresolved. First, the literature exhibits substantial conceptual fragmentation regarding the theoretical foundations of POE. Different studies employ varying theoretical perspectives, often without explicitly articulating how these perspectives inform instructional design and learning outcomes. Some investigations emphasize conceptual change, whereas others focus on inquiry learning, scientific reasoning, collaborative learning, or technology-enhanced instruction. As a result, the accumulated knowledge base lacks a coherent theoretical synthesis capable of explaining the evolution of POE research over time.

Second, considerable variation exists in the instructional design of POE implementations. Although the original model consists of the three stages of prediction, observation, and explanation, many contemporary studies incorporate additional elements such as experimentation, collaborative discussion, digital technologies, and project-based activities (Srisawasdi & Panjaburee, 2015). However, these modifications are often introduced independently and remain insufficiently integrated into a unified conceptual framework. Consequently, it remains unclear how these emerging instructional components collectively contribute to science learning.

Third, while POE has demonstrated effectiveness in promoting conceptual understanding, the traditional model does not explicitly address several competencies emphasized in contemporary educational frameworks. Twenty-first-century science education increasingly highlights collaboration, digital literacy, technological competence, and authentic inquiry as essential learning outcomes (Barak, 2016). Yet collaboration and technology integration are not formally embedded within the original Predict–Observe–Explain sequence. In many studies, they appear only as supplementary instructional supports rather than core pedagogical components. This limitation suggests the need for a reconceptualization of POE that aligns more closely with contemporary educational expectations.

Furthermore, existing review studies on POE have predominantly focused on measuring effectiveness in terms of achievement, conceptual understanding, or specific learning outcomes (Yatmanto et al., 2025). Although such reviews provide valuable evidence regarding the efficacy of POE, they offer limited insight into the broader theoretical evolution of the model, the diversity of instructional designs employed, and the implications of these developments for future science education practice. To date, no systematic review has comprehensively synthesized the theoretical foundations, instructional characteristics, and learning outcomes of POE while simultaneously proposing a conceptual framework that responds to the demands of twenty-first-century primary science education.

Addressing these gaps is important for both theoretical and practical reasons. Theoretically, a comprehensive synthesis can clarify the conceptual foundations that have shaped the development of POE research and identify emerging trends in science education. Practically, such a synthesis can guide educators and curriculum developers in designing learning environments that integrate conceptual understanding, scientific inquiry, collaboration, and technology use. Moreover, given the increasing emphasis on learner-centered and technology-enhanced education, there is a pressing need to develop instructional frameworks that extend beyond the traditional focus on conceptual change.

Based on these considerations, this study proposes a reconceptualization of the traditional POE model through the Predict–Investigation–Collaboration–Technology Application (PICOTA) framework. Unlike conventional POE, PICOTA positions investigation, collaboration, and technology application as central pedagogical dimensions rather than supplementary instructional features. The framework is grounded in constructivism, inquiry learning, social constructivism, and technology-enhanced learning theories, thereby reflecting contemporary perspectives on science learning in primary education.

The novelty of this study lies in three major contributions. First, it provides a comprehensive synthesis of the theoretical foundations underpinning POE research from 2010 to 2025. Second, it systematically examines how instructional designs and learning outcomes associated with POE have evolved over time. Third, and most importantly, it proposes the PICOTA framework as a new conceptual model that integrates investigation-based learning, collaborative learning, and technology application within the tradition of POE. This reconceptualization extends the scope of POE beyond conceptual change and positions it as a more relevant framework for addressing the educational demands of the twenty-first century.

Therefore, the objectives of this systematic literature review are: (1) to identify and analyze the dominant theoretical foundations underlying POE research in science education; (2) to examine the evolution of instructional designs and learning outcomes associated with POE implementation; and (3) to propose the Predict–Investigation–Collaboration–Technology Application (PICOTA) framework as a contemporary model for primary science education.

METHODS

Research Design

This study employed a Systematic Literature Review (SLR) to synthesize and critically evaluate the body of knowledge concerning the Predict–Observe–Explain (POE) model in science education. The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021), which provide a transparent and systematic framework for identifying, screening, selecting, and synthesizing relevant literature. The SLR approach was selected because it enables researchers to integrate findings from multiple studies, identify research trends, examine theoretical developments, and generate new conceptual understandings based on accumulated evidence. In the context of this study, the systematic review approach was considered appropriate for examining the theoretical foundations, instructional designs, and learning outcomes associated with POE, as well as for developing a reconceptualized framework, namely Predict–Investigation–Collaboration–Technology Application (PICOTA), that reflects contemporary demands in primary science education.

The literature search was conducted using three internationally recognized academic databases: Scopus, Web of Science (WoS), and Education Resources Information Center (ERIC). These databases were selected because they provide extensive coverage of high-quality educational research and are widely used in systematic review studies. The search focused on articles published between 2010 until 2025, allowing the review to capture developments in POE research over the last fifteen years.

To ensure comprehensive retrieval of relevant studies, several search strings were employed using combinations of keywords related to the POE model and science education. The primary search terms included "Predict Observe Explain," "POE strategy," "POE model," "Predict Observe Explain AND primary education," "Predict Observe Explain AND elementary science. The search process was restricted to peer-reviewed journal articles published in English. All records retrieved from the three databases were exported and managed using reference management software to facilitate screening and duplication removal.

Table 1. Search Databases and Keywords

Database	Search Keywords
Scopus	"Predict Observe Explain", "POE strategy", "POE model"
Web of Science	"Predict Observe Explain", "POE AND primary education",
ERIC	"Predict Observe Explain", "POE AND elementary science", "POE AND conceptual change"

Inclusion and Exclusion Criteria

Prior to the screening process, explicit inclusion and exclusion criteria were established to ensure the relevance and quality of the selected studies. Articles were included if they: (1) focused on the implementation, evaluation, or theoretical discussion of the Predict–Observe–Explain model or its modified forms; (2) were conducted within science education contexts; (3) reported empirical findings, theoretical analyses, or review findings relevant to the study objectives; (4) were published between 2010 and 2025; (5) appeared in peer-reviewed journals indexed in Scopus, Web of Science, or ERIC; and (6) were available in full-text format.

Conversely, studies were excluded if they: (1) did not focus primarily on POE; (2) were conference proceedings, book chapters, editorials, dissertations, theses, or unpublished reports; (3) were conducted outside science education contexts; (4) contained insufficient methodological information; or (5) represented duplicate publications. These criteria were applied consistently throughout the screening process to ensure methodological rigor and transparency.

Table 2. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Focus on POE or POE-based learning	Not focused on POE
Science education context	Non-science education context
Journal articles	Conference papers, theses, dissertations, editorials
Published between 2010–2025	Published before 2010
Full-text articles available	Incomplete articles
English language	Non-English publications

The diagram illustrates the article selection process for this systematic literature review (SLR) using the Scopus database. During the identification stage, 405 records relevant to the search keywords were identified. Of these, 57 records were removed before the screening process because they were outside the scope of the research topic. Consequently, 348 records proceeded to the screening stage. At this stage, 117 records were excluded because their document types were not journal articles (e.g., conference papers, book chapters, reviews, editorials, and other non-article publications), leaving 231 records for further consideration. Subsequently, during the retrieval stage, 120 records were not retrieved because they were published in languages other than English. As a result, 111 articles were assessed for eligibility. During the eligibility assessment stage, 33 articles were excluded because their full texts were not accessible to the researchers. Ultimately, 78 articles met all inclusion criteria and were included in the systematic literature review. These studies constituted the primary dataset used to investigate theoretical foundations, instructional designs, and learning outcomes associated with POE.

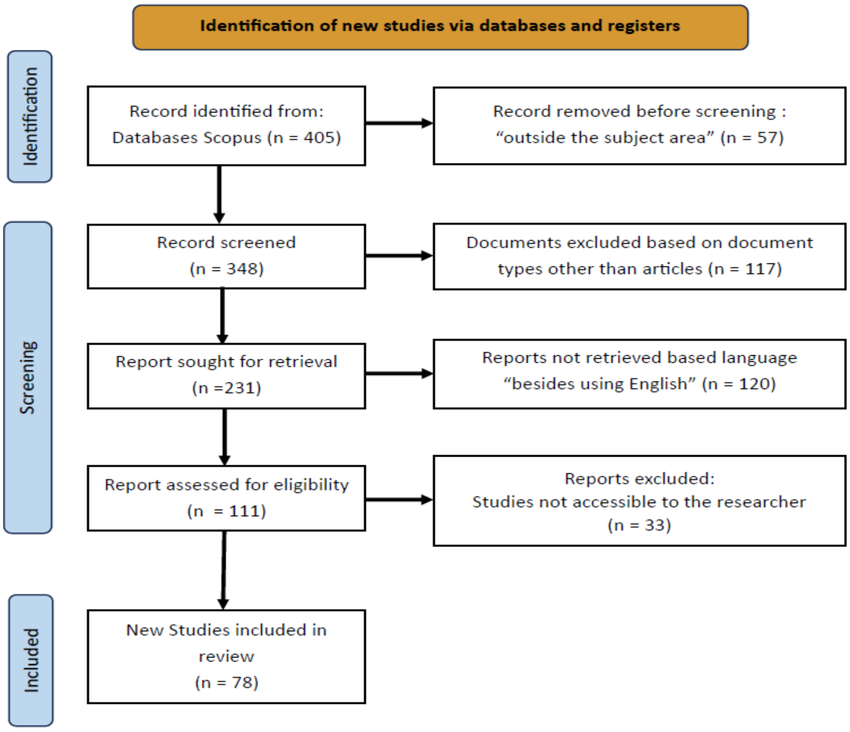

Figure 1. PRISMA 2020 Flowchart

A structured data extraction protocol was developed to ensure consistency in data collection across all selected studies. Each article was reviewed systematically, and relevant information was recorded using a standardized extraction form. The extracted data included publication information, country of study, educational level, research design, theoretical foundations, instructional characteristics, learning outcomes, collaboration elements, technology integration, and key findings.

Data Analysis

The selected studies were analyzed using thematic synthesis, following the procedures proposed by (Thomas & Harden, 2008). Thematic synthesis was selected because it allows researchers to integrate findings from diverse studies and generate higher-order conceptual interpretations. The analysis was conducted in three interconnected stages. The first stage involved open coding, in which all extracted data were carefully reviewed and coded according to recurring concepts, ideas, and findings. Codes were assigned to information related to theoretical foundations, instructional approaches, learning outcomes, collaboration practices, and technology integration.

The second stage focused on the development of descriptive themes. Similar codes were grouped into broader categories representing major areas of POE research. This process resulted in themes such as constructivism, conceptual change, inquiry learning, social constructivism, technology-enhanced learning, science process skills, critical thinking, communication skills, and collaborative learning. The final stage involved generating analytical themes by examining relationships among the descriptive themes and identifying broader patterns across studies. Through iterative comparison and synthesis, the researchers identified a progressive shift in POE research from a primary emphasis on conceptual change toward investigation-oriented, collaborative, and technology-supported learning. These findings provided the conceptual basis for proposing the Predict–Investigation–Collaboration–Technology Application (PICOTA) framework as a contemporary extension of the traditional POE model.

To enhance the credibility and trustworthiness of the findings, the coding and synthesis processes were conducted iteratively. Articles were reviewed multiple times to ensure consistency in interpretation and theme development. Any discrepancies identified during the analysis were revisited and resolved through further examination of the original studies. Several measures were implemented to ensure methodological rigor throughout the review process. First, the review adhered to the PRISMA 2020 guidelines to promote transparency and reproducibility. Second, explicit inclusion and exclusion criteria were established before the search and screening process commenced. Third, a standardized data extraction form was employed to maintain consistency across studies. Finally, thematic synthesis procedures were applied systematically to ensure that interpretations were grounded in the evidence extracted from the reviewed literature. Through these procedures, the study generated a comprehensive and reliable synthesis of the theoretical foundations, instructional designs, and learning outcomes associated with the Predict–Observe–Explain model. The resulting evidence served as the basis for developing the PICOTA framework, which aims to better align science learning with the demands of twenty-first-century primary education.

RESULTS AND DISCUSSION

The results of this systematic literature review are presented based on an analysis of eleven selected studies published between 2014 and 2024 that investigated the implementation of the Predict–Observe–Explain (POE) model in science education. The analysis focuses on identifying the dominant theoretical foundations, examining the evolution of instructional designs and learning outcomes, and exploring the challenges and limitations reported in previous studies. Table 3 presents the characteristics of the studies included in this systematic literature review, covering information on authors, publication year, country of origin, journal source, and indexing status.

Table 3. Summary of the collected studies author, publication year, country of origin, journal source, and indexing status

No	Author(s)	Country	Jurnal Name	Indexed By
1	(Zudaire et al., 2022)	Spanyol	International Journal of Early Childhood	Scopus (Q2)
2	(Nawaz et al., 2020)	Australia–USA	Journal of Learning Analytics	Scopus (Q1)
3	(Fitriani et al., 2020)	Indonesia	International Journal of Instruction	Scopus (Q2)
4	(Banawi et al., 2019)	Indonesia	International Journal of Instruction	Scopus (Q2)
5	(Vaara & Sasaki, 2019)	Finlandia–Brasil	LUMAT: International Journal on Math, Science and Technology Education	Scopus (Q1)
6	(Karamustafaoğlu & Mamlok-naaman, 2015)	Turki–Israel	Eurasia Journal of Mathematics, Science and Technology Education	Scopus (Q2)
7	(Yuenyong & Thathong, 2015)	Thailand	Mediterranean Journal of Social Sciences	Scopus (Q3)
8	(Kibirige et al., 2014)	Afrika Selatan	Mediterranean Journal of Social Sciences	Scopus (Q3)

9	(Mamun & Lawrie, 2023)	Australia–Bangladesh	Smart Learning Environments	Scopus (Q1)
10	(Hidayati et al., 2024)	Indonesia–Malaysia–Belanda	International Journal of Information and Education Technology	Scopus (Q3)

The studies reviewed were published between 2014 and 2024, indicating sustained scholarly interest in the Predict–Observe–Explain (POE) model over the past decade. Geographically, the research is distributed across various countries, including Indonesia, Malaysia, Australia, the United States, Spain, Finland, Brazil, Turkey, Israel, Thailand, Bangladesh, the Netherlands, and South Africa, demonstrating the international relevance of POE in science education research. Indonesia appears as the most prominent contributor, either independently or through international collaborations, highlighting the strong adoption of POE within the Indonesian educational context. Furthermore, all selected studies were published in reputable international journals, with the majority indexed in Scopus, including several journals ranked in Q1 and Q2 quartiles. This distribution suggests that the body of literature reviewed is academically rigorous and provides a reliable foundation for analyzing the theoretical development, implementation trends, and future directions of POE-based learning models. Table 4 summarizes the methodological characteristics of the studies included in this systematic literature review, including the main features of POE implementation, research designs, participants, and data collection methods.

Table 4. Summary of the main features of POE implementation, research designs, participants, and data collection methods

No	Author (Year)	Main Features	Research Design	Participants	Data Collection Methods
1	(Zudaire et al., 2022)	POE integrated with Inquiry-Based Science Education (IBSE) in preschool science project	Qualitative Classroom Intervention	Preschool students	Observation, Student Work Analysis, Teacher Reflection
2	(Nawaz et al., 2020)	Simulation-based POE environment to investigate confusion during learning	Learning Analytics Study	Undergraduate students	Log Data Analysis, Learning Analytics
3	(Fitriani et al., 2020)	Integration of PBL and POE (PBLPOE) to improve critical thinking and scientific attitude	Quasi-Experimental	132 senior high school students	Essay Test, Observation Checklist, Interview
4	(Banawi et al., 2019)	POE to improve conceptions of states of matter among pre-service teachers	Pre-Experimental	PGSD students	Five-Tier Diagnostic Test (Pretest-Posttest)
5	(Vaara & Sasaki, 2019)	POE mediated by video analysis for teaching kinematic graphs	Classroom Intervention Study	First-year engineering students	Concept Test, Student Worksheets
6	(Karamustafaoğlu & Mamlok-naaman, 2015)	POE for conceptual understanding in electrochemistry	Quasi-Experimental	40 university students	Open-Ended Test, Multiple-Choice Test
7	(Yuenyong & Thathong, 2015)	POE as constructivist teaching strategy for physics teacher development	Qualitative Study	5 physics teachers	Observation, Interview, Teaching Journal, Lesson Plan Analysis
8	(Kibirige et al., 2014)	POE to reduce misconceptions about dissolved salts	Quasi-Experimental	Grade 10 students	Pretest, Posttest, ANCOVA Analysis

9	(Mamun & Lawrie, 2023)	Online inquiry-based modules using POE structure	Mixed Methods	University students	Learning Analytics, Online Activity Records
10	(Hidayati et al., 2024)	Digital POE module with computer-assisted feedback	Quasi-Experimental	60 senior high school students	Questionnaire, Interview, Pretest-Posttest

Overall, the studies show that POE has been widely applied across different educational levels, from preschool to higher education. Most studies employed quasi-experimental and qualitative designs, with data collected through tests, observations, interviews, questionnaires, and learning analytics. The findings indicate that POE is commonly used to enhance conceptual understanding, conceptual change, critical thinking, and inquiry-based learning in science education. Table 5 summarizes the key challenges and limitations identified in previous studies on the implementation of the Predict–Observe–Explain (POE) model in science education.

Table 5. The key challenges and limitations on the implementation of the Predict–Observe–Explain (POE) model in science education

Aspect	Summary
Challenges	Strong student misconceptions that are difficult to change through a single intervention. Students often experience confusion during the observation phase when results differ from predictions. Teachers require adequate pedagogical skills to implement POE effectively. Limited digital literacy and technological infrastructure can hinder technology-enhanced POE implementation. POE activities generally require more classroom time than traditional instruction.
Limitations	Most studies involve small samples and are conducted in limited educational contexts. Research primarily measures short-term learning outcomes rather than long-term retention. Most studies focus on conceptual understanding, with limited attention to collaboration, creativity, and digital competence. Integration of advanced technologies (AI, AR, VR, Learning Analytics) remains underexplored. POE research is concentrated in physics and chemistry, with fewer studies in primary science education.

The reviewed studies indicate that although POE is effective in promoting conceptual understanding and conceptual change, several challenges remain, including persistent student misconceptions, cognitive confusion during learning, teacher readiness, technological constraints, and time-intensive implementation. In addition, existing research is limited by small sample sizes, short-term outcome measurements, a predominant focus on conceptual understanding, and limited exploration of collaboration, creativity, digital competence, and emerging technologies. Furthermore, POE research remains concentrated in physics and chemistry contexts, highlighting the need for broader applications in primary science education and technology-enhanced learning environments. Table 6 presents the key finding derived from the literature review and its implication for future research and instructional model development.

Table 6. The key finding derived from the literature review and its implication for future research and instructional model development

Finding	Implication
Limited integration of inquiry, collaboration, and technology in traditional POE	Need for the development of the PICOTA (Predict–Investigation–Collaboration–Technology Application) model to support 21st-century science learning.

Dominant Theoretical Foundations Underlying POE Research in Science Education

The findings of this systematic literature review indicate that the Predict–Observe–Explain (POE) strategy is predominantly grounded in constructivist learning theory. Across the reviewed studies, POE is consistently positioned as an instructional approach that encourages learners to actively construct knowledge by connecting prior experiences with new scientific evidence. The predict phase allows learners to externalize their existing conceptions, the observe phase confronts these conceptions through empirical evidence, and the explain phase facilitates conceptual restructuring through reflection and reasoning (Au et al., 2020). This sequence aligns closely with the constructivist perspective that learning occurs through the active construction and reconstruction of knowledge rather than passive information transmission (Taber, 2024). POE effectively promoted conceptual understanding in electrochemistry because students were encouraged to compare their predictions with observed outcomes and revise their explanations accordingly (Karamustafaoğlu & Mamlok-naaman, 2015).

The analysis further revealed that conceptual change theory serves as a secondary but highly influential theoretical foundation for POE implementation. Many studies emphasized the ability of POE to identify and remediate misconceptions by creating cognitive conflict between learners' prior beliefs and scientific observations (Mustofa et al., 2024). Research on dissolved salts showed that students exposed to POE experienced significant reductions in misconceptions compared to those receiving traditional instruction, supporting the argument that conceptual conflict is a critical mechanism for scientific learning. Similarly, POE successfully identified students' prior conceptions and facilitated conceptual revision, particularly when learners encountered discrepancies between their predictions and actual observations (Samsudin et al., 2024).

Another theoretical perspective emerging from the literature is inquiry-based learning. Several studies integrated POE within broader inquiry frameworks, positioning prediction, observation, and explanation as essential scientific inquiry processes (Hsiao et al., 2017). In preschool science education, for example, the POE strategy was embedded within inquiry-based science projects that encouraged learners to formulate hypotheses, conduct investigations, analyze results, and communicate explanations. These findings suggest that POE not only supports conceptual understanding but also cultivates fundamental scientific process skills such as questioning, observing, reasoning, and evidence-based argumentation (Spektor-levy et al., 2013).

The review also identified growing integration between constructivism and socio-constructivism. While earlier POE studies focused primarily on individual cognitive development, more recent research emphasizes collaborative meaning-making through discussion, peer interaction, and cooperative problem-solving (Hong et al., 2014). The emergence of hybrid models such as PBLPOE illustrates how researchers increasingly combine POE with collaborative learning approaches to strengthen critical thinking and scientific attitudes. These developments indicate an evolution from purely cognitive interpretations of learning toward socially mediated knowledge construction (Fitriani et al., 2020).

Evolution of Instructional Designs and Learning Outcomes Associated with POE Implementation

The review revealed a clear evolution in instructional designs involving POE over the past decade. Early implementations primarily utilized simple laboratory demonstrations designed to elicit students' misconceptions and facilitate conceptual change (Samsudin et al., 2024). These studies focused on individual learning processes and conceptual understanding within specific science topics such as electrochemistry, Newtonian mechanics, states of matter, and chemical dissolution. Results consistently demonstrated that students exposed to POE achieved higher conceptual understanding and lower levels of misconception than those taught using conventional methods (Banawi et al., 2019; Karamustafaoğlu & Mamlok-naaman, 2015).

Subsequent developments expanded POE into more sophisticated instructional environments. Researchers began integrating POE with active learning methodologies, video analysis, inquiry-based projects, and problem-based learning (Özcan & Uyanık, 2022). For example, the application of POE supported by video analysis enabled students to investigate kinematic graphs through authentic observation and interpretation activities, resulting in improved understanding of motion concepts and graphical representations. Likewise, inquiry-based preschool projects incorporated POE as a scaffold for scientific exploration, allowing young learners to engage meaningfully with scientific investigations (Zudaire et al., 2022).

A significant trend identified in recent studies is the integration of digital technologies into POE-based instruction. Digital modules, simulations, computer-assisted feedback systems, and online inquiry environments have become increasingly common. Research demonstrated that digital POE modules enhanced students' conceptual understanding of physics more effectively than traditional instructional approaches (Hidayati et al., 2024). Furthermore, online learning environments employing POE structures improved learner engagement when supported by appropriate scaffolding and instructional guidance. These findings indicate that technology integration has expanded the accessibility and effectiveness of POE beyond conventional classroom settings (Çırakoğlu et al., 2022).

The review also identified a broadening range of learning outcomes associated with POE implementation. While conceptual understanding remains the most frequently reported outcome, recent studies document positive effects on critical thinking, scientific attitudes, reasoning abilities, metacognitive awareness, engagement, and self-regulated learning (Hong et al., 2014). Combining POE with problem-based learning significantly improved students' critical thinking skills and scientific attitudes. Similarly, studies integrating POE with mathematical reasoning activities reported substantial improvements in students' reasoning performance. These findings suggest that POE has evolved from a conceptual change strategy into a comprehensive pedagogical framework capable of supporting multiple dimensions of twenty-first-century learning (Fitriani et al., 2020).

Reconceptualizing POE Through the PICOTA Framework

Based on the synthesis of theoretical foundations and instructional developments identified in this review, a new framework entitled Predict–Investigation–Collaboration–Technology Application (PICOTA) is proposed as an extension of traditional POE for contemporary primary science education. The findings indicate that while POE remains highly effective for promoting conceptual understanding and conceptual change, recent educational demands require additional dimensions that support inquiry, collaboration, digital literacy, and authentic problem-solving. Based on these findings, this review proposes the Predict–Investigation–Collaboration–Technology Application (PICOTA) framework as a reconceptualization of POE for twenty-first-century primary science education.

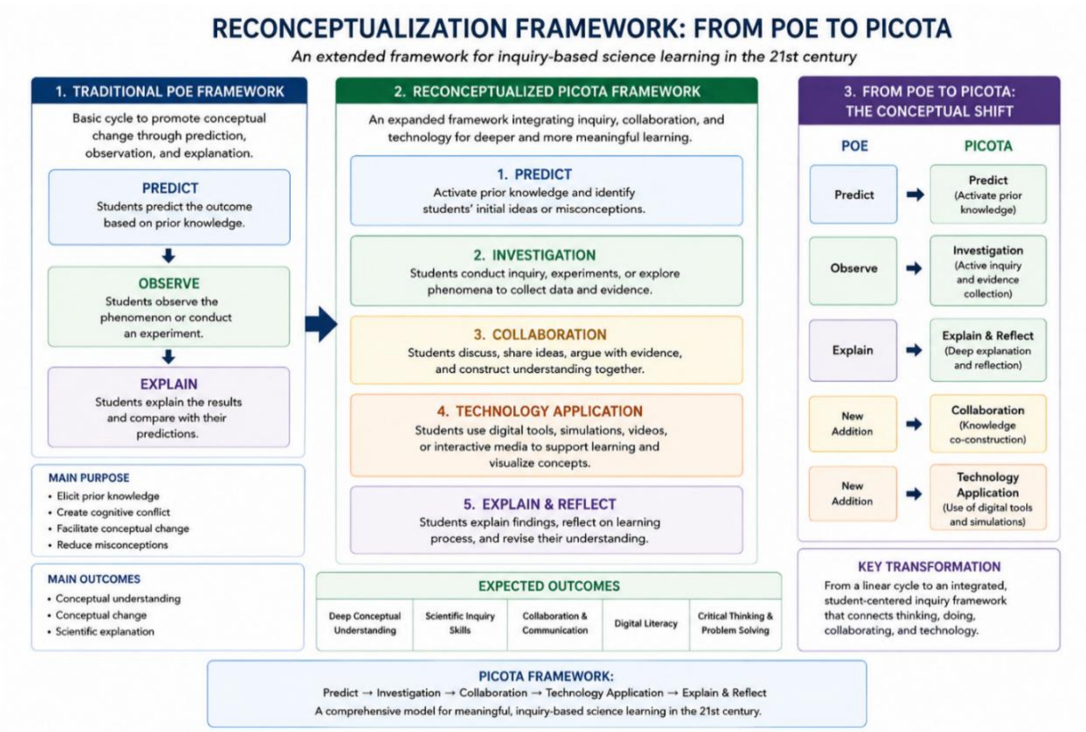

Figure 2. PICOTA Framework

The Predict stage in PICOTA retains the core strength of POE by activating students' prior knowledge and eliciting initial conceptions. Consistent with constructivist and conceptual change theories, prediction serves as the starting point for meaningful learning because students must articulate and justify their existing ideas before encountering new evidence. This phase helps teachers identify misconceptions and establish cognitive readiness for learning (Banawi et al., 2019; Mustofa et al., 2024).

The Investigation stage expands the traditional observe phase by emphasizing active inquiry and evidence collection. Rather than merely observing teacher demonstrations, students engage directly in scientific investigations, experimentation, data collection, and problem-solving activities (Pedaste et al., 2015). This modification reflects the growing influence of inquiry-based learning documented throughout the reviewed studies. Investigation encourages deeper engagement with scientific practices and aligns with current science education standards emphasizing authentic inquiry experiences.

The Collaboration stage introduces socio-constructivist principles into the learning process. The literature demonstrates that discussion, peer interaction, and collaborative problem-solving enhance conceptual understanding and scientific reasoning (Ramdani et al., 2016). Through collaboration, students compare interpretations, negotiate meaning, and construct shared understanding based on evidence. This component addresses the increasing emphasis on communication and teamwork as essential competencies in twenty-first-century education.

Finally, the Technology Application stage reflects the digital transformation evident in recent POE research. Technology functions not merely as a delivery tool but as a means of enhancing investigation, visualization, feedback, and communication (Chaijalearn et al., 2023). Digital simulations, interactive modules, virtual laboratories, and educational technologies enable students to explore scientific phenomena more deeply while supporting personalized and self-regulated learning (Huang et al., 2023). The inclusion of this component responds directly to evidence showing that technology-enhanced POE environments can improve engagement, conceptual understanding, and learning effectiveness.

Collectively, PICOTA represents a contemporary evolution of the traditional POE framework. It preserves the strengths of constructivist learning and conceptual change while incorporating inquiry, collaboration, and technology integration. Consequently, PICOTA offers a theoretically grounded and pedagogically relevant model for primary science education that aligns with the demands of twenty-first-century learning and supports the development of scientific literacy, critical thinking, collaboration skills, and digital competence.

This study contributes to science education research in several important ways. First, it provides a comprehensive synthesis of the theoretical foundations underpinning POE research over the last fifteen years. The findings demonstrate that POE has evolved from a model primarily grounded in conceptual change theory toward a multidimensional framework incorporating inquiry learning, social constructivism, and technology-enhanced learning. Second, the review reveals significant changes in instructional design, highlighting the increasing importance of investigation, collaboration, and technology integration. These findings provide a clearer understanding of how POE has been adapted to address emerging educational needs.

Third, this study introduces the PICOTA framework as a conceptual extension of POE. Unlike previous studies that examined individual modifications of POE, this review synthesizes evidence across multiple contexts and proposes an integrated framework that systematically incorporates investigation, collaboration, and technology application. Finally, the proposed framework offers practical implications for teachers, curriculum developers, and researchers seeking to design science learning environments that support conceptual understanding, scientific inquiry, collaborative learning, and digital competence simultaneously. Consequently, PICOTA represents a theoretically grounded and empirically informed model capable of addressing the challenges of twenty-first-century primary science education.

CONCLUSION

In conclusion, the findings of this systematic literature review indicate that the Predict–Observe–Explain (POE) model has evolved from a conceptual change strategy into a more comprehensive pedagogical framework in science education. The reviewed studies consistently demonstrate that POE is grounded in constructivism, conceptual change theory, inquiry-based learning, and social constructivism, and has proven effective in improving students' conceptual understanding, science process skills, critical thinking, scientific attitudes, and learning engagement. Furthermore, the implementation of POE has progressively incorporated investigation activities, collaborative learning, and digital technology integration. These findings suggest that the traditional POE model requires reconceptualization to better address the demands of twenty-first-century education. Accordingly, this study proposes the Predict–Investigation–Collaboration–Technology Application (PICOTA) framework as an extension of POE that systematically integrates scientific inquiry, collaboration, and technology-enhanced learning. The implications of this study are significant for teachers, curriculum developers, and researchers, as PICOTA can serve as a foundation for designing science learning environments that not only foster conceptual understanding but also promote scientific literacy, critical thinking, collaboration, and digital competence, which are essential skills for learners in the twenty-first century.

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