



Design and Practice of Cultivating Primary School Students' Scientific Explanation Ability Based on the POE Strategy

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Abstract: Against the backdrop of rapid technological advancement and accelerating knowledge iteration, scientific explanation ability, as a core component of scientific literacy, has become a fundamental competence influencing a nation's innovation capacity. This study, grounded in conceptual change theory and the theory-ladenness of observation, adopts a design-based research approach and integrates the Predict-Observe-Explain (POE) strategy with the Claim-Evidence-Reasoning (CER) framework. Through three iterative cycles, a "POE-CER" dual-cycle instructional model was constructed, and a three-month quasi-experimental study was conducted with two fourth-grade classes in a primary school in Beijing. The results indicate that this model, through a three-level cognitive scaffold comprising concept activation (prediction stage), evidence processing (observation stage), and knowledge reconstruction (explanation stage), significantly improves students' scientific explanation ability, particularly in the dimensions of evidence use and logical reasoning, while no statistically significant difference was observed in claim construction. The model was found to be particularly effective for boys with strong interest in scientific inquiry and high classroom participation, but showed limited effectiveness for students with weaker foundational knowledge.

Keywords: POE Strategy, Scientific Explanation Ability, Instructional Model

INTRODUCTION

Background

With the rapid advancement of science and technology and the accelerating pace of knowledge renewal, scientific literacy has become a key indicator of a nation's overall strength and global competitiveness. The ability to construct scientific explanations lies at the core of scientific literacy, requiring students to use scientific knowledge, methods, and reasoning to explain natural phenomena and scientific issues. *The Compulsory Education Science Curriculum Standards (2022 Edition)* highlight the importance of scientific explanation within four core competencies: scientific concepts, scientific thinking, inquiry practice, and attitudes and responsibility [1]. Scientific concepts emphasize the application of scientific principles to explain phenomena and solve real-world problems. Scientific thinking involves analyzing data through models, establishing connections between evidence and explanations, and generating reasoned conclusions. Inquiry practice focuses on the collection and analysis of evidence, as well as the formulation and explanation of conclusions. Attitudes and responsibility emphasize expressing ideas based on evidence and logical reasoning. Taken together, the ability to construct scientific explanations constitutes a fundamental competence in science education.

In the context of globalized education, fostering students' ability to construct scientific explanations has become a shared priority in science education. Curriculum standards in countries such as Canada [2], the United States [3], and the United Kingdom [4] all emphasize that students should be able to apply scientific knowledge to analyze and explain various phenomena. Similarly, China's *Opinions on Deepening Education and Teaching Reform and Comprehensively Improving the Quality of Compulsory Education* call for strengthening the development of scientific thinking and explanatory competence, highlighting its importance within national talent development strategies.

Classroom observations in primary school science indicate that students often demonstrate limited competence in constructing scientific explanations. They struggle to clearly articulate their interpretations of phenomena, frequently conflate description with explanation, and lack the ability to support claims with evidence and reasoning. These challenges can be attributed to several limitations in current instructional practices.

First, teaching objectives often focus on the mechanical acquisition of experimental results, while neglecting higher-order cognitive processes such as explanation and reasoning.

Second, classroom activities tend to emphasize observation and teacher-led explanation, providing limited opportunities for students to independently construct explanations. This results in fragmented conceptual understanding and weak problem-solving abilities.

Third, assessment practices prioritize knowledge recall, with insufficient attention to the evaluation of competencies such as scientific explanation and experimental design.

Moreover, evaluation is predominantly teacher-centered, lacking multi-dimensional feedback mechanisms such as self-assessment and peer assessment.

The Predict-Observe-Explain (POE) instructional strategy, proposed by White and Gunstone [5], provides a structured approach to engaging students in scientific inquiry. The three stages—prediction, observation, and explanation—correspond closely to the processes of claim, evidence, and reasoning, which are central to scientific explanation. As such, the POE strategy can effectively support students' active participation in inquiry processes and promote the development of scientific thinking.

Research Problem

Based on the above considerations, this study investigates the impact of POE-based instructional design on primary school students' ability to construct scientific explanations. Specifically, the study addresses the following research questions:

- (1) What are the points of alignment between the development of scientific explanations and the POE strategy?
- (2) How can effective instructional models and practical approaches be designed to support the development of scientific explanations among primary school students?
- (3) What assessment tools can be used to evaluate students' scientific explanations, and how can these be used to refine and improve POE-based instructional frameworks?

LITERATURE REVIEW

Research Status

Research on POE Strategy

The POE strategy is a student-centered instructional approach that actively engages learners in the process of scientific inquiry. In this framework, students first generate predictions based on their prior conceptions and everyday experiences. They then test these predictions through observation and experimentation, compare outcomes to identify discrepancies, and resolve cognitive conflict by constructing scientifically grounded explanations. This process facilitates conceptual change and supports the integration of knowledge.

The POE strategy also enables teachers to more effectively diagnose students' prior conceptions and identify the sources of misconceptions. Existing research, both domestic and international, has primarily focused on its role in conceptual construction, understanding, and transformation, with substantial evidence supporting its effectiveness in enhancing students' engagement in scientific inquiry.

Empirical studies have demonstrated the positive impact of the POE strategy on students' learning outcomes. For example, studies by Costu [6] and Karamustafaoglu [7] indicate that POE-based instruction can deepen students' understanding of scientific concepts and reduce misconceptions. In addition, research by Hong and colleagues shows that inquiry-based learning supported by mobile technologies can enhance primary school students' interest in science and their motivation to continue learning [8]. Studies conducted by Peng [9] and Liao [10] further demonstrate that applying the POE strategy in subjects such as chemistry and physics can promote conceptual construction, deepen understanding, and improve students' inquiry and problem-solving abilities.

Despite its demonstrated effectiveness, the application of the POE strategy has been concentrated primarily in secondary-level physics and chemistry education. Research on its implementation in primary school science remains relatively limited, indicating a need for further investigation in this context.

Research on Scientific Explanations

Research on scientific explanations spans both the fields of philosophy of science and science education. In the philosophy of science, although no unified theory of scientific explanation has been established, several influential models have been proposed, including the deductive-nomological model, the inductive-statistical model, the causal-mechanistic model, the unificationist model, and the pragmatic theory of scientific explanation [11]. In science education, multiple instructional frameworks have been developed to support students in constructing scientific explanations. One widely adopted framework is the Claim-Evidence-Reasoning (CER) model, derived from Toulmin's Argument Pattern. This framework, developed by researchers such as McNeill, organizes scientific explanation into three core components: claim, evidence, and reasoning. By providing structured scaffolding, the CER framework supports students in articulating explanations more systematically and reduces cognitive barriers in the explanation process [12]. Building on these theoretical foundations, Yao [13] proposed the Phenomenon-Theory-Data-Reasoning (PTDR) framework, which conceptualizes scientific explanation as an integration of four elements: the

phenomenon to be explained, relevant scientific theory, empirical data, and logical reasoning. This framework explicitly connects philosophical models of scientific explanation with educational practice [11]. In addition, Tang proposed the Premise-Reasoning-Outcome (PRO) framework, which conceptualizes scientific explanation in terms of three components: premise, reasoning, and outcome. This framework emphasizes the role of established scientific knowledge—such as facts, laws, and theories—as the basis for explanation, and highlights the importance of logical reasoning in linking theory with observable phenomena. Through this structure, students are supported in organizing and expressing scientific explanations in a more coherent and systematic manner [14].

Research on the Assessment of Scientific Explanations

In science education, assessing students' ability to construct scientific explanations is essential for understanding their learning progress and informing instructional improvement. Consequently, both domestic and international scholars have devoted increasing attention to the development of assessment frameworks aimed at enhancing the effectiveness of instruction in scientific explanation. One widely used approach is the CER framework, which has been extended to assessment contexts by categorizing students' explanations into hierarchical levels. In this framework, students' responses are evaluated based on the presence and quality of three components—claim, evidence, and reasoning—with scores assigned through systematic coding procedures [15]. Building on disciplinary competency frameworks, Yao and Guo [11] developed the Phenomenon-Theory-Data-Reasoning (PTDR) assessment framework, which evaluates scientific explanations across four dimensions: phenomenon, data, theory, and reasoning. Students' responses are scored according to a three-level rubric: absence of the element (0), inclusion with incorrect analysis (1), and inclusion with correct analysis (2). Similarly, the Premise-Reasoning-Outcome (PRO) framework proposed by Tang conceptualizes scientific explanation in terms of three components: premise, reasoning, and outcome. Within this framework, “premise” and “reasoning” are assessed across four levels (M-0-1-2), while “outcome” is evaluated across three levels (M-0-1). All components are assessed through structured coding of students' responses, enabling a systematic analysis of explanation quality [14]. Overall, these frameworks demonstrate a common trend toward structuring scientific explanation into analyzable components and employing rubric-based coding to evaluate students' explanatory competence.

Theoretical Foundations

This study is grounded in three theoretical perspectives: the theory-ladenness of observation, conceptual change theory, and the scientific inquiry process. These perspectives are closely aligned with the POE strategy and collectively provide a robust theoretical foundation for fostering students' ability to construct scientific explanations.

Theory-ladenness of Observation

The theory-ladenness of observation was proposed by the American philosopher of science Norwood Russell Hanson, who regarded it as a theory of knowledge acquisition that

emphasizes the role of observation in gaining knowledge [16]. Observation is not entirely objective; rather, it is deeply influenced by the observer's prior knowledge, experience, and theoretical background. Theory shapes both the focus and the objects of observation and serves as essential guidance for the proper conduct of observational activities [17]. This perspective holds that observation should be purposeful, systematic, and norm-governed, with appropriate theoretical guidance ensuring its objectivity. This view aligns closely with the "observe" phase of the POE instructional model, in which students develop an intuitive understanding of concepts through observing experimental phenomena and then use collected evidence to explain their predictions, thereby embodying the core idea of theory-laden observation.

Conceptual Change Theory

Conceptual change refers to the process by which learners reorganize their existing knowledge structures when confronted with information that is inconsistent with their prior conceptions. This process is typically initiated by cognitive conflict and involves the subsequent resolution of discrepancies between existing understanding and new evidence. Students' prior conceptions, which are formed through everyday experiences and prior learning, often differ from scientifically accepted concepts. Accordingly, learning can be understood as a process of transforming prior conceptions into scientifically valid understandings [18]. According to Posner's conceptual change model, conceptual change occurs under four key conditions: dissatisfaction with existing conceptions, and the intelligibility, plausibility, and fruitfulness of new conceptions [19]. Instructionally, this process begins with eliciting students' prior conceptions, followed by the introduction of discrepant events to induce cognitive conflict. This, in turn, motivates learners to reconsider and revise their existing understanding. Scientific concepts are then introduced to resolve the conflict, thereby facilitating conceptual change. The effectiveness of this process depends on the extent to which new conceptions are understandable, credible, and useful to learners. Consequently, teachers play a critical role in diagnosing students' prior conceptions and identifying the sources of misconceptions, in order to support meaningful conceptual restructuring. This theoretical perspective provides a strong foundation for the "prediction" phase of the POE strategy. During this phase, students are encouraged to articulate their prior conceptions and generate predictions based on their existing understanding. The discrepancies between predictions and subsequent observations create cognitive conflict, which serves as a driving force for conceptual change.

Scientific Inquiry Process

Science education aims to develop students' scientific literacy and their engagement in scientific inquiry. According to the *Compulsory Education Science Curriculum Standards (2022 Edition)*, scientific inquiry can be conceptualized as an iterative process consisting of eight key stages: posing questions, formulating hypotheses, designing investigations, collecting evidence, analyzing and interpreting data, drawing conclusions, communicating findings, and reflecting on the inquiry process [1]. This process emphasizes students' active participation and highlights the importance of applying scientific methods in authentic

contexts. Through engagement in these inquiry practices, students not only acquire scientific knowledge but also develop scientific thinking and inquiry competencies.

RESEARCH DESIGN

This study adopts a design-based research (DBR) approach to investigate the impact of the POE strategy on students' ability to construct scientific explanations. The study was conducted with fourth-grade primary school students in Beijing and incorporated quasi-experimental elements within an iterative design framework. Through multiple cycles of design, implementation, analysis, and refinement, the effectiveness and underlying mechanisms of the POE strategy were systematically examined.

Research Methods

Design-based Research

Design-based research (DBR) emphasizes the iterative refinement of educational interventions in authentic learning environments through close collaboration between researchers and practitioners [20]. It typically involves cyclical phases of analysis, design, implementation, and evaluation. In this study, the POE-based instructional design was refined through three iterative cycles. In the first cycle, the intervention was implemented to familiarize students with the instructional procedures, and preliminary adjustments were made based on classroom observations and student feedback. The second cycle focused on addressing identified challenges and optimizing instructional strategies to better support student engagement and understanding. In the third cycle, the refined instructional model was systematically implemented to evaluate its effectiveness.

Quasi-experimental Research Method

Quasi-experimental research is widely used in educational settings to examine the effects of instructional interventions under natural classroom conditions, particularly when random assignment is not feasible [21]. In this study, two intact classes from a primary school in Beijing were selected, with no significant differences in prior academic performance. One class was assigned as the experimental group and received instruction based on the POE strategy, while the other served as the control group and received conventional instruction. A pretest-posttest design was employed to assess students' ability to construct scientific explanations. The assessment data were coded using the CER framework and analyzed statistically to evaluate the effectiveness of the POE-based intervention and to inform instructional improvement.

Questionnaire Survey Method

The questionnaire survey method is a way to collect data by presenting questions in writing. Researchers formulate the questions they want to study into questionnaires and ask respondents to complete them to understand their views and opinions on a certain phenomenon or issue [22]. This study uses the questionnaire survey method to understand fourth-grade students' awareness of their own level of scientific explanation ability.

Interview Method

Interviews are a research method in which researchers conduct purposeful conversations with research subjects using pre-prepared questions or outlines. They use face-to-face meetings, telephone calls, video calls, and tools such as pen and paper and voice recorders to collect firsthand data and obtain information from the research subjects [23]. In this study, after analyzing the pre- and post-test results, a sample of research subjects was randomly selected from the experimental class for interviews to understand their views and feelings about the teaching model based on the POE strategy.

Research Process Design

This study aimed to improve primary school students' scientific explanation ability using the POE strategy. It employed a combined "Design-Based Research (DBR) + quasi-experiment" approach, as shown in Figure 1.

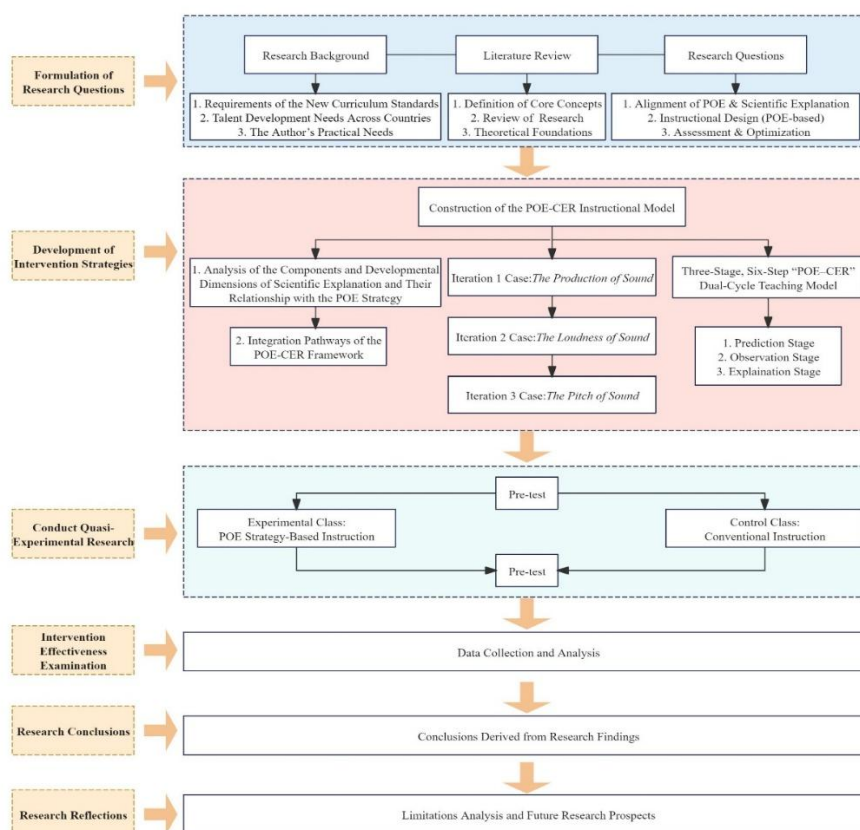


Figure 1: Research Flowchart.

First, a pre-test confirmed that there was no significant difference in scientific explanation ability between the experimental and control groups. Then, by analyzing the components and developmental dimensions of scientific explanation ability and their relationship with the POE strategy, the study focused on the deep integration of the POE teaching strategy and the cultivation of scientific explanation ability. A dual-cycle teaching model of "Predict-Observe-Explain-Claim-Evidence-Reasoning" (POE-CER) was systematically constructed. The study deconstructed the cognitive dimensions of scientific explanation

ability (claim construction, evidence identification, and logical reasoning), establishing a mapping relationship with the abilities at each stage of the POE strategy. The design was optimized through three rounds of iteration. Next, a one-semester quasi-experiment was conducted. The experimental group spent the first month familiarizing themselves with the optimized POE teaching model and then formally implemented the model during the following two months. The control group used conventional teaching throughout. Finally, post-tests were used to collect and code data to analyze and verify the effectiveness of the POE teaching model, forming a subject-adaptive implementation framework.

Research Tools

The research tools include a scientific explanation ability test, a scientific explanation ability assessment framework, and a responsive interview outline. These tools are used to collect data from the experimental and control groups before and after the experiment to evaluate the effectiveness of the teaching model.

Scientific Explanation Ability Test Questions

Dimensions and Structure of Test Questions:

The scientific explanation ability assessment tool developed in this study strictly follows the CER framework and employs a two-stage (pre-test/post-test) equivalent design. Each stage consists of five open-ended situational questions based on real scientific phenomena, covering three dimensions: claim construction, evidence application, and logical reasoning. Each dimension is evaluated using a three-level scoring scale (0-2 points).

The test items were adapted from scientific explanation-related tasks in PISA [24], past question banks from experimental schools, and assessment instruments developed by scholars such as Meng [25], Chen [26], and Gao [27]. Following expert review and revision, the instrument aligns with science education standards and is appropriate for students' cognitive levels.

Validity Assurance:

Based on the data collected in the preliminary survey, factor analysis was conducted to examine construct validity, as shown in Table 1.

Table 1: KMO and Bartlett's test.

KMO and Bartlett's test		
KMO measure of sampling adequacy		.633
Bartlett's test of sphericity	Approximate chi-square	385.471
	Degrees of freedom	78
	Significance	.000

The KMO value was 0.633, exceeding 0.6, and the approximate chi-square value was relatively large at 385.471. The significance value (Sig.) was 0.000, which is far below 0.05,

indicating that the data are suitable for factor analysis. Three common factors with eigenvalues greater than 1 were extracted, corresponding to the three dimensions of the assessment and consistent with the expected structure, thereby supporting the construct validity of the test items.

Scientific Explanation Ability Assessment Framework

Dimensions and Structure of Assessment Framework:

This study adopts McNeill's CER framework for assessing scientific explanation levels to develop scoring criteria and constructs an assessment system for elementary school students' scientific explanation abilities based on actual teaching practices. This framework categorizes students' scientific explanation levels into three levels (0, 1, and 2) and assigns scores to the three elements of claims, evidence, and reasoning in students' scientific explanations based on their responses.

Considering the cognitive characteristics of fourth-grade students, the claim dimension is scored as 0 or 1 point, with 1 point awarded for a correct answer and 0 points for an incorrect or missing answer. The evidence and reasoning dimensions are scored on a scale of 0, 1, and 2 points. Each question includes all three dimensions (claim, evidence, and reasoning), with a maximum score of 5 points per question. Both the pre-test and post-test consist of five questions, with a total possible score of 25 points.

Validity Assurance:

This study adopts the widely recognized CER framework for assessing scientific explanation levels, developed by McNeill, as the basis for constructing the scoring criteria. Numerous scholars, including Tian [28], Wang [29], Min [30], and Hu [31], have applied this framework in their research and provided evidence supporting its validity, integrating it with local teaching practices.

Responsive Interview Outline:

Based on students' scientific explanation ability assessment data and their responses, an interview outline was developed, and targeted interviews were conducted with selected students. The responsive interview outline aimed to explore students' thought processes and the difficulties they encountered during scientific explanation. During the interviews, teachers encouraged students to express their views and explain their reasoning, while also examining the causes of atypical and typical responses in the assessment. By collecting first-hand qualitative data, common problems among students were identified, providing support for the optimization and adjustment of teaching intervention strategies and ultimately contributing to the development of students' scientific thinking abilities.

Research Subjects and Selection

This study included two fourth-grade classes (Class 1 with 38 students and Class 5 with 39 students) from a primary school in Beijing. The two classes had similar student numbers,

gender ratios, and academic performance. Class 1 served as the experimental group, implementing the POE teaching strategy, while Class 5 served as the control group, receiving conventional instruction. The teaching content consisted of the “Sound” and “Motion and Force” units from the fourth-grade science textbook. As control variables, the teaching content and teachers were consistent across both classes. Before the experiment, a pretest of scientific explanation ability was administered to students in both classes. A total of 77 test papers were distributed and collected. SPSS analysis indicated that the data were normally distributed, meeting the assumptions of the independent samples t-test. Subsequently, with class as the grouping variable, the overall scientific explanation ability and each dimension were compared between the two classes to determine whether there were significant differences.

The results of the independent samples t-test are presented in Table 2. The significance values for overall scientific explanation ability and each component (claim, evidence, and reasoning) in both classes were all greater than 0.05, indicating no significant differences and thus meeting the basic conditions for a quasi-experimental study.

Table 2: Independent-samples t-test of pre-test data on scientific explanation ability between experimental class and control class.

		Levene's test for equality of variances		t-test for equality of means		
		F	Sig.	t	df	Sig. (2-tailed)
Scientific explanation ability	Equal variances assumed	.040	.843	.912	75	.364
	Equal variances not assumed			.912	74.422	.365
Claim construction ability	Equal variances assumed	5.448	.022	.672	75	.504
	Equal variances not assumed			.675	66.548	.502
Evidence identification ability	Equal variances assumed	.218	.642	.359	75	.720
	Equal variances not assumed			.359	74.983	.720
Reasoning ability	Equal variances assumed	1.052	.308	1.333	75	.186
	Equal variances not assumed			1.330	71.763	.188

INSTRUCTIONAL DESIGN AND PRACTICE

Constituent Elements, Cultivation Dimensions of Scientific Explanation Ability and Its Intrinsic Logical Relationship with POE

The POE strategy consists of three stages: prediction, observation, and explanation. From a stage-based perspective, scientific explanation ability can be divided into the ability to construct claims, identify evidence, and engage in reasoning. From a component-based perspective, scientific explanation ability includes four dimensions: disciplinary knowledge,

critical thinking, reasoning ability, and knowledge reorganization and reconstruction. The alignment between scientific explanation ability and the POE strategy is mainly reflected in the support provided by each stage of the POE strategy for the development of scientific explanation ability, as demonstrated through systematic connections at three levels.

The prediction stage focuses on activating prior conceptions and constructing claims. Based on conceptual change theory, teachers create problem situations to activate students' prior conceptions and existing experiences, stimulate cognitive conflict, induce dissatisfaction with prior conceptions, and trigger learning motivation. Students use disciplinary knowledge to construct claims, identify relationships among variables, and develop testable hypotheses. Teachers support students in forming logical and verifiable conjectures through group discussions and thinking scaffolds. This stage emphasizes cultivating students' standardization and operability in claim construction, laying a foundation for the subsequent explanation stage.

The observation stage focuses on the acquisition and processing of empirical data. Based on the theory-ladenness of observation, students collect data through purposeful and standardized observation and experimental operations. By employing experimental designs with controlled variables, using measurement tools appropriately, selecting valid data, and utilizing observation records, students improve the reliability and validity of data and enhance their data recording and analysis abilities. This provides reliable evidence for scientific explanation and develops students' ability to identify evidence.

The explanation stage centers on logical reasoning and knowledge reorganization and reconstruction. Students compare their predictions with observation results and explain the experimental predictions based on empirical evidence, such as phenomena and data collected during the experiment. If the results are consistent, students deepen their understanding of knowledge; if inconsistent, they resolve cognitive conflicts through scientific concepts and achieve conceptual change. By establishing connections between experimental phenomena and scientific concepts through logical reasoning, students develop their inductive and deductive abilities, advance from describing phenomena to explaining underlying principles, and accomplish knowledge reorganization and reconstruction.

The POE strategy adopts a progressive structure of “triggering cognitive conflict, supporting empirical data, and deepening logical reasoning.” It dynamically and cyclically forms a spiral developmental pathway for scientific explanation ability, promoting the transformation of learners' scientific thinking from empirical cognition to systematic and conceptual understanding. This teaching paradigm aligns with students' cognitive development and the core elements of scientific inquiry, providing an operable practical pathway for the systematic cultivation of scientific explanation ability.

A Teaching Model for Cultivating Primary School Students' Scientific Explanation Ability: Based on the POE Strategy

In classroom teaching, the POE strategy can be integrated into scientific inquiry to cultivate students' scientific explanation ability, as illustrated in Figure 2.. In the prediction stage, students predict experimental phenomena based on their existing knowledge and experience. Teachers should identify students' prior conceptions according to conceptual

change theory and grasp their knowledge levels, thereby laying the foundation for conceptual change. In the observation stage, students collect evidence through experiments. Based on the theory-ladeness of observation, students need to actively learn observation methods to improve the efficiency and depth of observation. When observations are consistent with predictions, students connect new knowledge with prior knowledge; when inconsistent, cognitive conflict is triggered. The process of resolving such conflict is the process of conceptual change, which motivates students to explore and integrate new knowledge with their original cognition. From observation to explanation, critical thinking and reasoning ability support students in completing knowledge reorganization and reconstruction. If students struggle to form explanations and draw conclusions, teachers should provide guidance in terms of disciplinary knowledge, thinking ability, and other aspects.

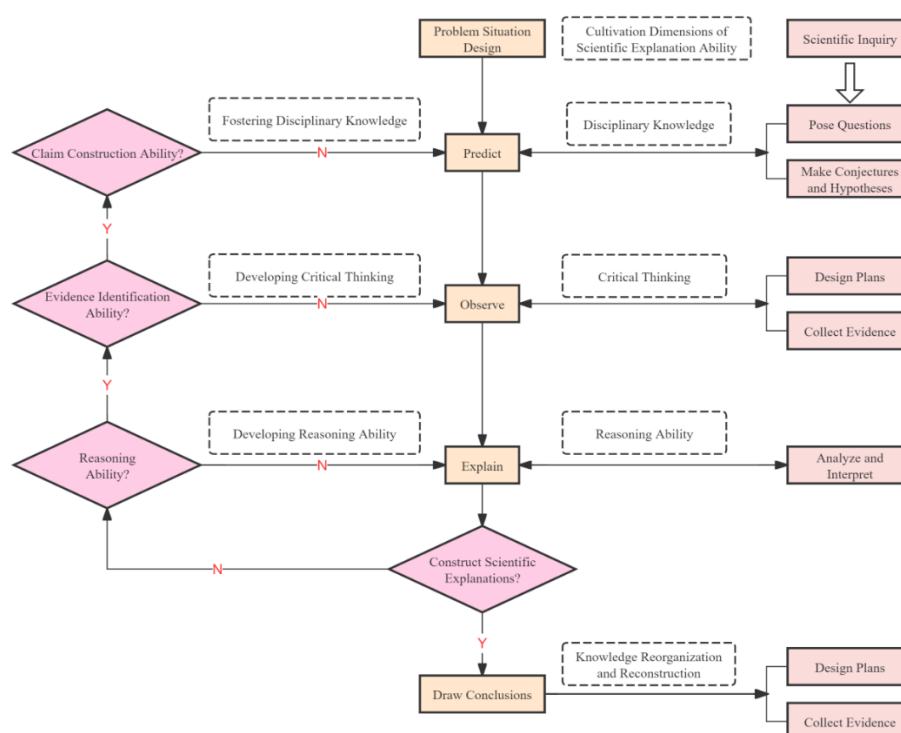


Figure 2: Teaching Flowchart for Cultivating Scientific Explanation Ability.

To enhance students' scientific explanation ability, the POE strategy can be integrated with the CER framework to explore an integrated model of "POE outer cycle plus CER inner cycle", as shown in Figure 3. The outer cycle follows the main teaching sequence of prediction-observation-explanation, while the inner cycle embeds targeted training in Claim-Evidence-Reasoning at each stage, forming a progressive structure of "macro POE encompassing micro CER." In the prediction stage, after students construct claims, the CER inner cycle is applied. Students identify evidence based on life experience and disciplinary knowledge and conduct preliminary reasoning to revise their claims and conjectures. In the observation stage, students observe experimental phenomena and collect data, followed by the embedded CER cycle, which guides them to identify and supplement valid evidence and adjust their reasoning processes. In the explanation stage, students integrate predictions and evidence to conduct in-depth reasoning and form a complete CER chain. Through group

peer assessment, they critically reflect on their own explanations to refine reasoning and promote knowledge reconstruction.

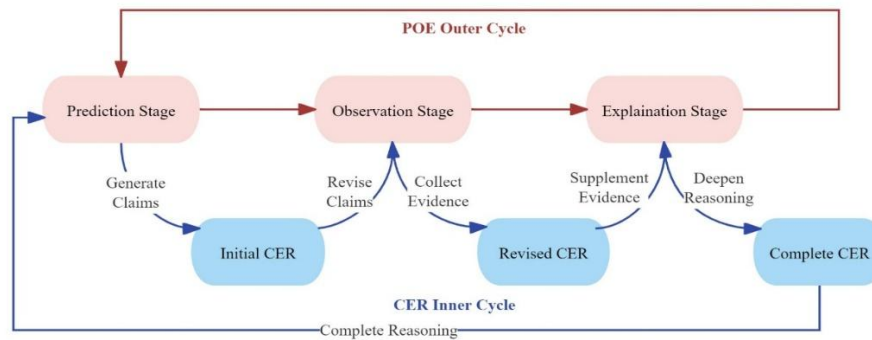


Figure 3: The Integration Path of "POE-CER".

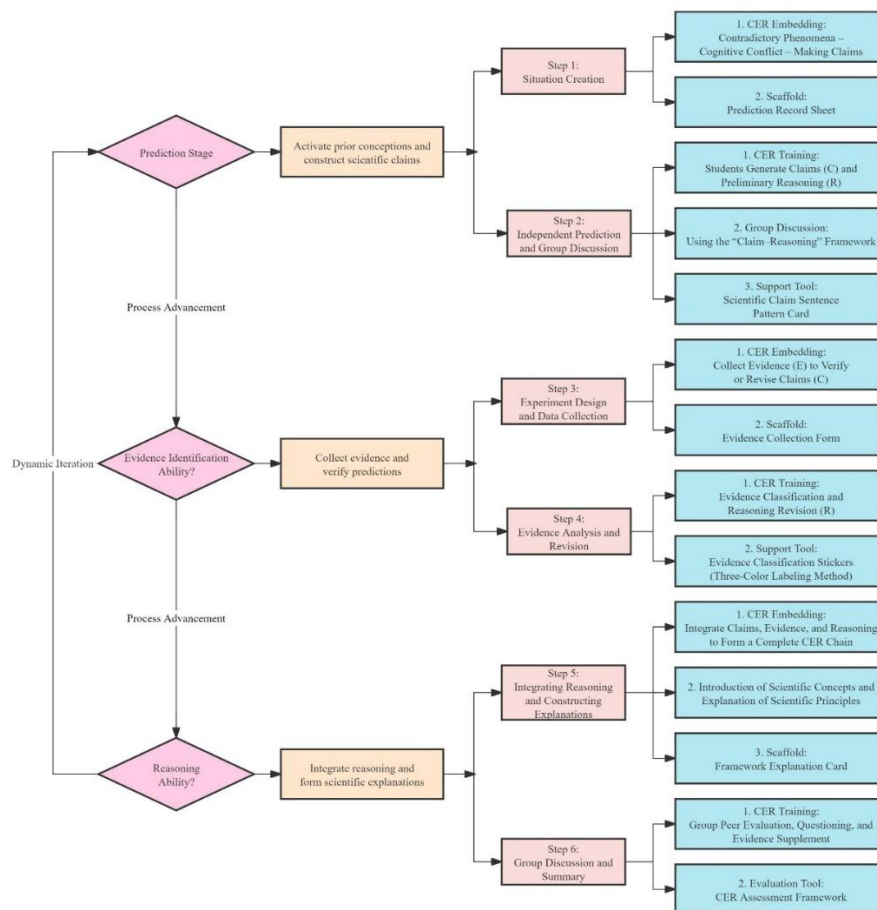


Figure 4: Construction of the "POE-CER" Dual-Cycle Teaching Model.

Through an in-depth exploration of the integration pathway of the "POE outer cycle + CER inner cycle," a POE-CER dual-cycle teaching model is constructed. Grounded in the basic process of scientific inquiry, this model takes the three stages of the POE strategy as its framework and embeds the CER scientific explanation framework, forming a three-stage, six-step teaching process, as shown in Figure 4.

Teaching Practice Process

This study constructed a three-stage, six-step “POE-CER” dual-cycle teaching model based on the POE strategy. To verify the effectiveness of this model, the teaching implementation was carried out in three rounds. After each round, the teaching strategies were gradually adjusted and improved based on students' classroom performance, after-class feedback, and instructors' comments. The experimental group received instruction designed around the POE strategy, which was continuously refined through design-based research, while the control group received conventional teaching.

In accordance with the teaching schedule of the experimental school, three units were selected: *The Production of Sound*, *The Loudness of Sound*, and *The Pitch of Sound*. In the first round, *The Production of Sound* focused on the nature of material vibration. By observing the causal relationship between object vibration and sound production, students established a basic framework for scientific explanation. In the second round, *The Loudness of Sound* introduced the variable of amplitude. On the basis of confirming that vibration produces sound, students' ability to explain the relationship between changes in physical quantities and phenomena was further developed. In the third round, *The Pitch of Sound* involved the concept of frequency, requiring students to analyze the more abstract relationship between waveform characteristics and auditory perception. Each round of activities included the following three stages.

Prediction Stage—Activate Prior Conceptions and Construct Scientific Claims

Stage One consists of two steps: Step 1: Situation Creation, and Step 2: Independent Prediction and Group Discussion. In the situation creation step, the teacher designs problem situations based on conceptual change theory to activate students' prior conceptions, trigger cognitive conflict through contradictory phenomena, and guide students to put forward preliminary conjectures by embedding the CER framework. In the independent prediction and group discussion step, training using the CER framework is introduced. Students first complete prediction sheets independently, engaging in claim construction (C), identifying potential evidence from daily experience (E), and conducting preliminary reasoning (R) in sequence.

Taking the lesson *How Is Sound Produced?* as an example, the prediction record sheet is shown in Figure 5. Afterwards, group discussions are conducted using a “claim-reasoning” structure. During the discussions, the teacher guides students to use scientific claim sentence patterns such as “I predict that... because...”. Through questioning and peer critique within groups, students' prior conceptions are revealed, promoting deeper reflection on their claims and stimulating curiosity. Students learn from one another in group discussions, revise their conjectures, and construct more scientifically grounded claims.

Claim (C)	Potential Evidence (E)	Preliminary Reasoning (R)
Sound is produced by the collision of objects	The drumstick strikes the drumhead when playing the drum	Collision causes objects to produce sound

Figure 5: Prediction Record Sheet.

Observation Stage—Collect Evidence and Verify Predictions

Stage Two consists of two steps: Step 3: Experiment Design and Data Collection, and Step 4: Evidence Analysis and Revision. In the experiment design and data collection step, students design experiments based on their predictions, with the CER framework embedded. They collect evidence (E) through experiments to verify or revise their claims (C) and complete an evidence collection form, as shown in Figure 6. In the evidence analysis and revision step, training using the CER framework is implemented. Students analyze experimental phenomena and data in depth, compare predictions with actual results to verify initial conjectures, revise their reasoning (R) based on experimental outcomes, and complete a revision record sheet, as shown in Figure 7.

During this process, teachers guide students to conduct standardized experimental operations and properly control variables. In accordance with the theory-ladenness of observation, students are instructed to carefully observe experimental phenomena and record data objectively to ensure the authenticity and validity of the data. When students revise their reasoning, teachers provide feedback and guidance to help them avoid misunderstandings, strengthen the logical connection between evidence and claims, and improve their scientific thinking and inquiry abilities.

Phenomenon Description	Vibration Occurred	Sound Produced
Stationary Rubber Band	No	No
Plucked Rubber Band	Yes	Yes

Figure 6: Evidence Collection Form.

Revised Claim (C)	Supplementary Evidence (E)	Deepened Reasoning (R)
Sound is produced by the vibration of objects	Sound is produced when the rubber band vibrates	Vibration → Air Transmission → Sound Formation

Figure 7: Revision Record Sheet.

Explanation Stage—Integrate Reasoning and Form Scientific Explanations

Stage Three consists of two steps: Step 5: Integrating Reasoning and Constructing Explanations, and Step 6: Group Discussion and Summary. In the step of integrating reasoning and constructing explanations, students synthesize experimental data and phenomena, apply the CER framework to systematically organize their reasoning processes, form logically rigorous scientific explanations, and clearly articulate the connections among claims, evidence, and reasoning. They also complete a framework explanation card, as shown in Figure 8.

In the group discussion and summary step, groups conduct peer review, questioning, and supplementation using the CER framework and ultimately reach a consensus to achieve conceptual change and knowledge reorganization and reconstruction. Teachers provide feedback and guidance from the dimensions of claims, evidence, and reasoning to help

students refine their explanations. Finally, teachers summarize the learning content, guide students to understand the nature of science, and raise new questions to connect to the subsequent POE cycle, thereby laying a foundation for the next scientific inquiry. Teachers should also encourage students to apply scientific concepts in daily life to enhance the concretization of knowledge and application ability.

Claim (C)	Evidence (E)	Reasoning (R)
Sound is produced by the vibration of objects	1. Sound is produced when the rubber band vibrates; 2. The vibrating tuning fork splashes water droplets	The vibration of the object drives the surrounding air to vibrate, forming sound waves that travel into the human ear

Figure 8: Framework Explanation Card.

After three rounds of teaching practice, students not only participated in class discussions more actively and proactively, but also improved their scientific explanation ability. In the first round, students could only describe phenomena in simple terms, such as “the desk makes a sound when tapped.” By the second round, they learned to record and analyze data: “the harder the tap, the greater the vibration amplitude, so the sound is louder.” In the third round, they were able to construct complete explanations by integrating evidence and principles: “the shorter the steel ruler, the faster it vibrates; faster vibration leads to higher pitch, so the shorter steel ruler has a higher vibration frequency and produces a higher-pitched sound.” Through three rounds of iterative optimization, the teaching model became basically mature. Subsequently, the experimental group continued to use the POE-CER dual-cycle teaching model based on the POE strategy, while the control group received conventional teaching. The teaching content was the unit Motion and Forces, and the experiment lasted for one semester.

RESEARCH RESULTS

After the teaching intervention was implemented, students in both the experimental and control groups were assessed on their scientific explanation abilities. A total of 77 test papers were distributed and collected, including 39 from the control group and 38 from the experimental group. The assessment results were coded and analyzed using SPSS software. After the completion of the sound unit, a unit test was conducted in accordance with the experimental school’s teaching schedule. The test questions were uniformly prepared by the school’s science teachers.

Effectiveness Analysis of the POE Strategy in Cultivating Primary School Students' Scientific Explanation Ability

Analysis of the Influence and Effectiveness of the POE Strategy on Scientific Explanation Ability

The post-test data, based on the scientific explanation ability test items and the assessment framework scale, were coded and analyzed using SPSS. The results indicated that the data were normally distributed, meeting the assumptions of the independent-samples t-test.

With class as the grouping variable, differences in students' overall and dimensional scientific explanation abilities between the two classes were compared. The results of the independent-samples t-test are presented in Table 3.

Table 3: Independent-Samples t-Test of Post-Test Scores for Each Dimension of Scientific Explanation Ability in the Experimental Class and Control Class.

		Levene's test for equality of variances		t-test for equality of means		
		F	Sig.	t	df	Sig. (2-tailed)
Scientific explanation ability	Equal variances assumed	6.338	.014	5.788	75	.000
	Equal variances not assumed			5.751	59.588	.000
Claim construction ability	Equal variances assumed	1.574	.214	.693	75	.491
	Equal variances not assumed			.694	74.550	.490
Evidence identification ability	Equal variances assumed	.349	.556	4.161	75	.000
	Equal variances not assumed			4.151	71.919	.000
Reasoning ability	Equal variances assumed	9.214	.003	6.951	75	.000
	Equal variances not assumed			6.901	56.772	.000

The data indicate that there is a significant difference between the two classes in overall scientific explanation ability ($t = 5.788$, $p < 0.01$), suggesting that the teaching method based on the POE strategy is significantly more effective than conventional teaching in improving students' overall scientific explanation ability. Regarding each dimension, the experimental group performed significantly better than the control group in evidence identification ability ($t = 4.161$, $p < 0.01$) and reasoning ability ($t = 6.951$, $p < 0.01$), highlighting the advantages of the POE strategy in fostering students' scientific observation and logical reasoning abilities. However, no statistically significant difference was found between the two groups in claim construction ability ($t = 0.693$, $p > 0.05$), indicating that the POE strategy has a limited effect on this ability.

Effectiveness Analysis of the POE Strategy on Primary School Students' Academic Achievement

Upon completion of the sound unit, a school-wide standardized unit test consisting of objective items, with a full score of 100, was administered to assess the academic performance of students in both classes. Normality tests conducted in SPSS indicated that the data from both the experimental and control groups were normally distributed, satisfying the assumptions for an independent-samples t-test. With class as the grouping variable, score differences between the experimental group ($n = 38$) and the control group ($n = 39$) were compared, and the results are presented in Table 4.

Table 4: Independent-Samples t-Test of Academic Achievement between the Experimental Class and the Control Class.

		Levene's test for equality of variances		t-test for equality of means		
		F	Sig.	t	df	Sig. (2-tailed)
Academic performance	Equal variances assumed	.212	.647	2.938	75	.004
	Equal variances not assumed			2.939	74.984	.004

According to the results of the independent-samples t-test, there was a statistically significant difference in academic achievement between the experimental group ($n = 38$, $M = 90.18$, $SD = 4.46$) and the control group ($n = 39$, $M = 87.18$, $SD = 4.51$). Levene's test for homogeneity of variances yielded $F = 0.212$, $p = 0.647$, satisfying the assumption of equal variances. Therefore, the equal-variance t-test results were adopted: $t(75) = 2.938$, $p = 0.004$ (two-tailed), with an effect size of Cohen's $d = 0.67$. The average score of the experimental group was significantly higher than that of the control group by 3.00 points, indicating that the teaching intervention based on the POE strategy had a significant positive effect on improving students' academic achievement ($p < 0.01$). The similar standard deviations indicate that the internal score dispersion of the two groups was comparable, which enhances the reliability of the conclusion.

Growth Analysis of the POE Strategy in Promoting the Development of Scientific Explanation Ability

A paired-samples t-test was used to compare the differences in the experimental group's scientific explanation ability and its sub-dimensions before and after the implementation of the POE teaching strategy. The results are shown in Table 5.

Table 5: Paired-Samples t-Test of Pre-Test and Post-Test Scientific Explanation Ability and Its Sub-Dimensions in the Experimental Class.

Group	Pre-test($M \pm SD$)	Post-test($M \pm SD$)	t	p(two-tailed)	Cohen's d
Scientific explanation ability	15.18 \pm 3.328	20.00 \pm 4.230	-6.116	0.000	0.992
Claim construction ability	4.66 \pm 0.481	4.84 \pm 0.437	-1.865	0.070	0.303
Evidence identification ability	6.26 \pm 1.639	8.11 \pm 1.886	-4.824	0.000	0.782
Reasoning ability	4.26 \pm 1.589	7.05 \pm 2.241	-7.047	0.000	1.143

The experimental group showed a statistically significant difference in scientific explanation ability between the pre-test and post-test (pre-test: $M = 15.18$, $SD = 3.328$; post-test: $M = 20.00$, $SD = 4.230$; $p < 0.01$, $d > 0.8$), with a large effect size. Significant differences were also found in evidence identification ability (pre-test: $M = 6.26$, $SD = 1.639$; post-test: $M = 8.11$, $SD = 1.886$; $p < 0.01$, $0.5 < d < 0.8$) and reasoning ability (pre-test: $M =$

4.26, SD = 1.589; post-test: M = 7.05, SD = 2.241; $p < 0.01$, $d > 0.8$), indicating a medium effect size and a large effect size, respectively. No statistically significant difference was observed in claim construction ability (pre-test: M = 4.66, SD = 0.481; post-test: M = 4.84, SD = 0.437; $p > 0.05$, $d < 0.5$). In summary, the POE strategy significantly improved students' overall scientific explanation ability, as well as their evidence identification and reasoning abilities, but had no statistically significant effect on enhancing claim construction ability.

Classified Tracking and Individualized Analysis of Students in the Experimental Class

To explore the effect of the POE strategy on improving the scientific explanation ability of different types of students, this study quantified individual progress in the experimental group using scientific explanation ability scores and the pre-post differences (Δ values) across three dimensions. Based on the Δ values of scientific explanation ability, the top 25% were classified as the high-progress group, whose scores were significantly higher than the class average; the middle 50% were classified as the medium-progress group, whose scores were comparable to the class average; and the bottom 25% were classified as the low-progress group, whose scores showed no significant improvement or even a decline.

Differential Analysis of the Impact Levels on the Experimental Class

The mean Δ values for each group in scientific explanation ability and its dimensions were calculated to establish a comparative baseline, and the results are presented in Table 6. To visually illustrate differences in progress across groups and dimensions, the data were transformed into a multidimensional comparative bar chart, as shown in Figure 9.

Table 6: Mean Improvements in Scientific Explanation Ability and Its Sub-Dimensions Among Different Categories of Students.

Group	Mean Δ of Scientific Explanation Ability	Mean Δ of Claim Construction Ability	Mean Δ of Evidence Identification Ability	Mean Δ of Reasoning Ability
High progress group (n=10)	9.7	0.6	4	5.1
Medium progress group (n=19)	4.8	0.15	1.8	2.8
Low progress group (n=9)	0.8	-0.22	0.5	0.1

Comparative analysis revealed that the high-progress group achieved significantly greater improvements in scientific explanation ability than both the medium-progress and low-progress groups, particularly in evidence identification and reasoning abilities. The medium-progress group exhibited slight improvements across all dimensions, whereas the low-progress group showed no significant improvement and even declined in certain dimensions, which may be attributed to their relatively weaker subject knowledge foundation. Within-group Δ -mean analysis indicated that reasoning ability showed the most

substantial improvement. The prediction, observation, and explanation components of the POE strategy effectively enhanced students' empirical awareness and their ability to construct logical chains. In contrast, improvement in claim construction ability was comparatively limited, which may be associated with the scoring criteria and format of the test items.

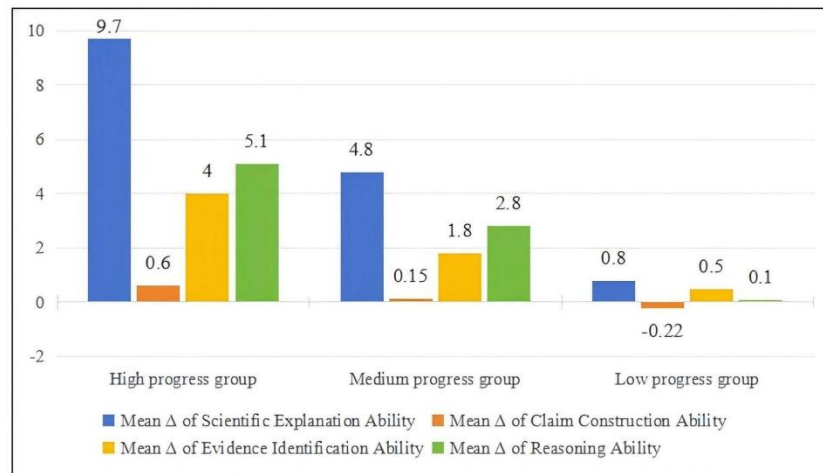


Figure 9: Multi-dimensional Comparative Bar Chart of Mean Improvements Among Different Categories of Students.

In conclusion, the POE strategy exerts differential impacts on students at different achievement levels and across different ability dimensions. Consequently, more targeted teaching strategies are needed to facilitate comprehensive improvements in students' abilities.

Analysis of Characteristics of Students in Different Categories

Based on classroom observations, post-class interviews, and teacher consultations, this study explored the relationship between student characteristics and the identified progress groups. The findings revealed that the 10 students in the high-progress group were all boys with average or below-average pre-test scores, yet they demonstrated a strong interest in scientific inquiry. They exhibited proactivity and quick thinking in classroom interactions and experiments, actively posed questions and tested hypotheses, and demonstrated a strong spirit of inquiry and practical abilities.

For students with average or below-average pre-test scores, although they possessed a certain subject foundation, they showed weaknesses in evidence analysis and logical reasoning. Under the guidance of the POE strategy, these students effectively analyzed evidence through its collection and classification during the observation and explanation phases and combined this with predictions to engage in logical reasoning. This approach significantly enhanced their critical thinking and knowledge reconstruction abilities, leading to substantial improvements in evidence identification and reasoning abilities. The medium-progress group had a balanced gender ratio, average pre-test scores, and a serious learning attitude, yet lacked depth and initiative in inquiry. The low-progress group was divided into two subgroups: one subgroup demonstrated strong academic performance and high scientific literacy, achieving high scores in both pre- and post-tests with limited room for

improvement; the other subgroup had a weak subject foundation, low classroom participation, and a lack of independent inquiry. These students relied more on teacher guidance, adapted slowly to the POE strategy, and thus showed no significant improvement.

Teaching Optimization and Reflection for Classified Students

The POE strategy exerts differential impacts on students at different levels, which necessitates differentiated instructional design. For high-progress students, the focus should be on strengthening inquiry-based learning and designing open-ended questions to cultivate their critical thinking. For medium-progress students, attention should be paid to their learning bottlenecks, stimulating their interest in active inquiry and guiding them to raise questions and express diverse viewpoints through peer review. For high-performing students within the low-progress group, higher-order tasks should be assigned to cultivate their higher-order thinking abilities. Meanwhile, more scaffolding support should be provided for students with weak foundations to consolidate their basic knowledge, enhance their classroom participation, and help them gradually adapt to the self-directed inquiry model.

The POE strategy also has varying impacts across different competency dimensions, allowing for targeted training in these areas. Training in claim construction can strengthen the standardized expression of scientific claims, while case analyses involving examples of excellence and areas for improvement can enhance students' self-assessment abilities. Through targeted training, students can develop a clearer understanding of the structure of scientific claims, learn to use evidence to support their viewpoints, and gradually improve the rigor of their logical reasoning.

Meanwhile, dynamic feedback and grouping mechanisms are integrated into the teaching process. Formative assessments, such as peer review and timely teacher feedback, are embedded in each phase of the POE strategy. Instruction is adjusted based on real-time progress data, and dynamic grouping ensures that students develop in an appropriate learning environment to meet their individual learning needs.

CONCLUSIONS AND REFLECTIONS

Conclusions

The POE Strategy Is Generally Effective in Improving Scientific Explanation Ability

This study adopted a quasi-experimental design to verify the effectiveness of a POE strategy-based teaching model in improving students' scientific explanation ability. The experimental group showed significant improvements in overall scientific explanation ability, as well as in evidence identification and reasoning abilities.

This finding is consistent with the view proposed by scholars such as Lu [32], Yang [33], and Lv [34], who argue that the POE strategy promotes conceptual change through cognitive conflict and empirical verification. The distinction of this study lies in its integration of the CER framework into each phase of the POE strategy, which strengthened the explicit cultivation of students' logical reasoning abilities.

POE Effectiveness Depends on Student Characteristics and Implementation

This study found that the effectiveness of the POE strategy in enhancing scientific explanation ability depends on its mode of application and students' prior ability characteristics, with evident differences across student groups and implications for teaching adaptability. Specifically, the POE strategy had the most significant effect on male students with moderate pre-test scores but strong interest and high engagement in scientific inquiry, while its effect was limited for students with weak foundations and for high-achieving, stable-performing students.

Scholars such as Shi [35] and Fu [36] have found that POE-based teaching can significantly improve students' academic performance and learning interest. This suggests that the application of the POE strategy should take into account the heterogeneity of student groups. Differentiated instructional designs should be developed for different students, with particular emphasis on their inquiry interest and level of participation.

For students with weak foundations, instructional scaffolding and tiered tasks can be incorporated, drawing on the research of scholars such as Shan [37], Hsu [38], McNeill [39], and Dong [40]. For high-achieving, stable-performing students, it is necessary to deepen the level of inquiry, design more challenging tasks, and further enhance their scientific thinking and innovative abilities.

Promotion of Scientific Explanation Ability Development by the POE Strategy: Differences Across Ability Dimensions

The experimental group showed no significant improvement in the claim construction dimension. This finding differs from the conclusions of scholars such as Ruiz-Primo [41], Yi [42], Liu [43], and Wang [44], who argue that the POE strategy can significantly improve students' ability to construct claims through prediction-generating activities. The discrepancy may be attributed to differences in research participants and assessment design. Most of these studies focused on senior high school students, who possess more mature cognitive structures and are capable of engaging in complex prediction construction, thereby demonstrating higher-level thinking in claim generation. In contrast, the present study targeted fourth-grade students, and the assessment items emphasized judging the rationality of given claims rather than open-ended claim construction. Although this design limited the expression of claim generation, it was consistent with the cognitive development stage of younger students.

Meanwhile, studies by Zhao [45], He [46], Hu [31], and Wu [47] have shown that primary and secondary school students generally exhibit no significant improvement in claim construction under different teaching strategies. This may be related to the cognitive development stage and the depth of reasoning training among younger students. Therefore, logical reasoning training should be strengthened progressively to gradually enhance students' ability to construct scientific claims.

Reflections

This study also has certain limitations. Only two instructional units were selected, and the experimental period lasted for only one semester. Due to the relatively short duration and

limited scope of the practical activities, such a short-term intervention makes it difficult to comprehensively evaluate the long-term instructional effects of the POE strategy. In addition, the research sample was limited to two fourth-grade classes from a primary school in Beijing, which constrains the generalizability of the findings to schools with similar contexts. Furthermore, the POE strategy did not yield sufficient improvement for students with weak foundational knowledge.

To address these limitations, future research can be optimized in four ways: implementing large-unit and interdisciplinary teaching to overcome content constraints; extending the research period to examine long-term effects; expanding the sample of teachers and students to enhance the generalizability of the findings; and refining instructional design while strengthening support for students with weak foundations.

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