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Quantitative Evaluation of Primary School Science Instructional Design Oriented toward Higher-Order Thinking Development

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Abstract: The 2022 Compulsory Education Science Curriculum Standards place higher-order thinking at the center of primary science education. Teachers, however, have few practical tools for assessing whether a lesson plan actually supports its development. This study develops an evaluation index for this purpose. A review of the literature and the curriculum standards produced six dimensions: teaching objectives, learner analysis, teaching process and methods, problem and situation design, thinking cultivation activities, and resource and technology application. These dimensions comprise sixteen second-level indicators. Their weights were estimated with the analytic hierarchy process (AHP), and the judgment matrices met the consistency requirement (CR < 0.1). The respective weights of the six dimensions were 0.2477, 0.1643, 0.2003, 0.1763, 0.1657, and 0.0458. Teaching objectives grounded in core competencies therefore received the greatest weight. The resulting framework offers teachers a structured way to review and improve lesson plans before teaching. The paper also outlines several directions for evaluating students' higher-order thinking in the classroom.

Keywords: Primary School Science; Instructional Design; Higher-Order Thinking; Quantitative Evaluation; Analytic Hierarchy Process; Deep Learning

1. Introduction

Higher-order thinking—commonly associated with analyzing, evaluating, and creating in the revised taxonomy of educational objectives [1]—has become an important concern in primary science education. The Compulsory Education Science Curriculum Standards (2022 Edition) [2] (hereafter, the "2022 Standards") give particular attention to scientific and higher-order thinking. Meeting this requirement begins before the lesson itself: teachers need plans that translate broad thinking goals into purposeful learning activities.

Reviewing a lesson plan before it is used can reveal weaknesses that may otherwise affect classroom learning. This is especially important for novice teachers, who often consult lesson plans found online but may have difficulty judging their quality. The present study therefore develops an evaluation index that teachers can use to select, review, and revise primary science lesson plans designed to foster higher-order thinking.

Primary science provides a particularly relevant setting for this work. Its content is closely connected with observation, experimentation, modeling, and explanation, all of which can support complex thinking when they are designed purposefully. The same activities, however, can be reduced to following instructions or confirming a known answer. Whether a lesson develops higher-order thinking therefore depends less on the presence of an experiment than on the intellectual work pupils are asked to do. This distinction underlies the present study: the index evaluates how the components of a lesson plan work together to create opportunities for reasoning, rather than simply checking whether familiar teaching activities are mentioned.

2. Problems in Current Primary School Science Instructional Design

Primary science instructional design in China continues to evolve, but several recurring problems remain [3].

2.1 Fragmentation of the Four-Dimensional Objectives

Teachers sometimes address scientific concepts, scientific thinking, inquiry practice, and attitude and responsibility as separate objectives rather than as connected aspects of learning. A lesson may, for example, present scientific facts without giving pupils opportunities to build understanding through inquiry or collaboration. Scientific interest and habits of mind may likewise be left implicit. The resulting design is likely to feel fragmented and overly focused on content delivery.

2.2 Unclear Orientation of Thinking Objectives

Although the 2022 Standards emphasize thinking, this emphasis is not always carried through from stated objectives to planned activities. Teachers may list several thinking objectives yet provide no situation, task, or question through which pupils can meet them. A plan might claim to develop analytical ability, for instance, while asking pupils only to recall information. Classroom questioning presents a related difficulty: without carefully sequenced prompts and anticipated guidance, the intended thinking process remains largely aspirational.

2.3 Irrational Thinking Evaluation Methods

Evaluation is often confined to checking factual knowledge through exercises completed after class. Such an approach gives little information about how pupils reason during learning. Some teachers attempt process-based assessment, but the procedures described in their plans may be too vague or demanding to use in practice. A workable mechanism for evaluating higher-order thinking is therefore still needed.

3. Theoretical Research Related to Higher-Order Thinking

3.1 Research on Deep Learning Theory

Higher-order thinking is closely associated with deep learning. Clarifying this relationship provides a useful theoretical basis for the evaluation framework developed below.

The objectives of deep learning. Deep learning involves making sense of new ideas, connecting them with prior and cross-disciplinary knowledge, and using them to address unfamiliar or authentic problems. Learners take an active role: they question information, select strategies, monitor their understanding, and revise their ideas. These processes support metacognition, problem solving, critical thinking, and creativity [4]. The aims of primary science education overlap substantially with these outcomes. A classroom that seeks to develop higher-order thinking must therefore move beyond the transmission and recall of isolated facts.

The connotation of deep learning. The literature highlights several features of deep learning: critical engagement with content, integration of ideas, reflection on learning, and the transfer of knowledge to new problems [5]. These features are related rather than independent. Pupils are more likely to transfer knowledge when they understand relationships among ideas and reflect on how and why a solution works. In this sense, deep learning provides both a route to, and evidence of, higher-order thinking in science.

McTighe and Silver similarly describe deep learning as the link between acquiring knowledge and developing competence. They argue that challenging tasks and thinking tools can help learners construct meaning and build the capacity to transfer and extend what they know [6].

3.2 The Connotation of Higher-Order Thinking

Higher-order thinking is commonly traced to Bloom's taxonomy, although the term is defined in different ways. The 2022 Standards describe scientific thinking as "a way of cognition, from a scientific perspective, of the essential attributes, inherent laws, and interrelationships of objective things" [2]. In primary science, pupils often move from direct experience toward explanation: they observe a phenomenon, identify patterns, and use evidence to form more abstract ideas. Imagination helps them propose possibilities, while abstract reasoning helps them test and organize those possibilities. The two processes work together rather than in isolation. For the purposes of instructional design, higher-order thinking can be considered in terms of analytical, evaluative, and creative thinking, each associated with observable learning behaviors [7]. These behaviors give teachers a basis for designing suitable tasks and prompts.

Recent work drawing on Bloom's taxonomy identifies model construction and application, scientific argumentation and reasoning, critical thinking and innovation, and interdisciplinary problem solving as central components of scientific higher-order thinking [8]. Unlike recall and basic comprehension, these components require pupils to use, examine, or extend knowledge.

3.3 Strategies for Cultivating Higher-Order

Thinking in Primary School Science Classrooms

3.3.1 Establishing objectives for higher-order thinking cultivation

Planning for higher-order thinking should begin with what pupils can already do. Teachers need to consider how well pupils describe observations, compare evidence, explain relationships, and evaluate claims. Objectives can then be pitched at an appropriate level and linked to observable learning behaviors. In a single lesson, a broad aim such as "develop analytical thinking" is not sufficiently precise unless the plan also indicates what pupils will analyze and how their analysis will be demonstrated.

3.3.2 Taking inquiry-based teaching as the primary approach

The 2022 Standards characterize science as a practical, comprehensive subject and identify inquiry practice as a core competency. They accordingly recommend organizing teaching around inquiry [2]. Research also associates inquiry-based learning with the development of higher-order thinking. Inquiry is therefore not simply an activity format; it is a way of engaging pupils in asking questions, using evidence, and revising explanations.

Studies of inquiry-oriented practical work likewise suggest that authentic tasks can support analysis, evaluation, and creation [9].

During inquiry, teacher guidance remains important. Well-timed questions can help pupils notice evidence, reconsider an assumption, or explain a choice without taking control of the investigation away from them. A lesson plan should therefore anticipate both opportunities for independent and collaborative work and points at which support may be needed. The amount of structure should reflect the learning objective and pupils' prior experience.

An inquiry-based lesson plan should make this sequence visible rather than merely label an activity as "inquiry."

3.3.3 Carefully creating problem situations

Scientific thinking often begins with a puzzling phenomenon or a worthwhile question. Situations should be accessible from pupils' experience but rich enough to create uncertainty and invite investigation. Observations, experiments, investigations, model making, stories, images, and short videos can all serve this purpose. The medium matters less than the thinking it elicits. Questions should also form a coherent sequence: an opening question establishes the problem, later prompts direct attention to evidence, and follow-up questions support explanation and transfer. Games or competitions may increase participation, but they should remain connected to the scientific problem rather than become ends in themselves.

A productive problem situation arouses curiosity while giving pupils something specific to investigate and discuss. Its value lies in the reasoning it supports, not simply in making the lesson lively.

3.3.4 Providing a free learning environment

The 2022 Standards ask teachers to provide opportunities for independent inquiry and collaborative discussion [2]. Pupils may, for example, help devise a procedure, clarify the task with peers, carry out an investigation, and compare interpretations of the evidence. Such participation engages cognition, emotion, and action together and makes pupils' thinking available for discussion.

Openness is particularly important when pupils are expected to question an explanation or propose an original idea. Teachers can support this by allowing more than one plausible approach, inviting pupils to explain disagreements, and treating mistakes as material for further inquiry. A classroom in which pupils fear criticism is unlikely to produce candid questions or adventurous hypotheses [3]. Freedom, however, does not mean an absence of structure; clear goals and respectful discussion norms give pupils the security to take intellectual risks.

Taken together, these studies suggest that a lesson plan should connect explicit thinking objectives with inquiry, purposeful problem situations, opportunities for pupil autonomy, and activities that make different forms of thinking observable.

3.4 From Theoretical Principles to Observable Design Features

The literature reviewed above points to three connected principles. First, higher-order thinking requires a knowledge base. Pupils cannot analyze evidence or evaluate an explanation without relevant concepts and experience. The distinction between lower- and higher-order thinking should therefore not be interpreted as a choice between knowledge and thinking. Well-designed instruction helps pupils acquire knowledge and then reorganize, question, and apply it. Second, thinking develops through activity. An objective written in a plan has little practical value unless pupils encounter a task that requires the intended process. Third, teachers need evidence of that process. Questions, intermediate products, dialogue, and revisions can reveal how pupils reach an answer and not merely whether the final answer is correct.

These principles also explain why alignment is central to evaluation. A plan may contain a demanding objective but a routine recall task, or it may include an open investigation without specifying what pupils are expected to learn from it. In both cases, the individual components appear reasonable while the design as a whole is weak. Alignment requires a traceable path from the analysis of learners to the objective, from the objective to the activity, and from the activity to evidence of learning. The six dimensions developed in this study examine different points along that path. Their purpose is not to prescribe a single lesson format, but to help reviewers determine whether the plan forms a coherent argument about how learning is expected to occur.

4. Construction of the Evaluation Index System

4.1 Establishing the Evaluation Dimensions of Instructional Design

An instructional design document sets out how curriculum requirements and knowledge of learners will be translated into classroom activity. A primary science plan commonly covers the teaching content, learner characteristics, objectives, key and difficult points, resources, methods, lesson sequence, and board work; reflection is usually added after the lesson. Drawing on these components, deep-learning theory, the 2022 Standards, and the discussion in Section 3.3, this study organized the index into six dimensions: teaching objectives, learner analysis, teaching process and methods, problem and situation design, thinking cultivation activities, and resource and technology application. The correspondence is direct. Objectives and learner analysis establish the intended level and focus of thinking; process and methods address inquiry and pupil autonomy; problem and situation design concerns the contexts that elicit reasoning; thinking cultivation activities target particular forms of thought; and resources and technology support these elements.

Teaching objectives are examined in terms of their grounding in core competencies, their orientation toward higher-order thinking, and their attainability through the planned activities.

Learner analysis considers pupils' existing thinking characteristics and readiness for the planned learning.

Teaching process and methods cover the structure of inquiry, the use of varied methods, and opportunities for pupils to exchange ideas and work autonomously.

Problem and situation design considers whether questions guide and extend thinking and whether situations are meaningful, authentic, and conducive to knowledge transfer.

Thinking cultivation activities are assessed according to the type of thinking they invite. Observation and comparison may support analysis; critique and discussion may support evaluation; and open design or explanation tasks may support creativity.

Resource and technology application concerns whether materials and technologies are chosen and integrated in ways that serve the learning goals.

4.2 Construction of the Evaluation Index Framework

Table 1 presents the resulting evaluation framework.

The indicators were developed through an iterative conceptual process. Candidate features were first drawn from the recurring problems identified in primary science lesson planning, the account of deep learning in Section 3.1, the forms of higher-order thinking discussed in Section 3.2, and the teaching strategies summarized in Section 3.3. Overlapping features were then grouped according to the component of instructional design to which they most directly referred. For example, authenticity and relevance were placed under problem and situation design, whereas opportunities for discussion were placed under teaching process and methods. The resulting categories were checked for conceptual separation while retaining links among them. This procedure produced the six first-level dimensions and sixteen second-level indicators in Table 1.

The unit of evaluation is the written instructional design rather than the teacher or the completed lesson. Each criterion should therefore be judged from evidence contained in the plan and its supporting materials. A reviewer should not assume, for example, that a teacher will ask productive follow-up questions if such questions or guidance strategies are absent from the document. At the same time, the index should not reward length for its own sake. A concise plan can provide strong evidence when its objectives, tasks, questions, and assessment points are specific and mutually consistent. This clarification is important because the framework is intended to improve the quality of planning, not to encourage unnecessary paperwork.

Table 1. Evaluation Dimensions of Primary School Science Instructional Design

First-level dimension	Second-level indicator	Evaluation criterion
Teaching Objectives	Objective establishment	Objectives are grounded in the relevant core competencies
	Objective orientation	Objectives explicitly target higher-order thinking
	Objective attainment	Planned activities provide a credible route to the stated objectives
Learner Analysis	Assessment of students' thinking	The analysis identifies pupils' existing thinking characteristics
	Assessment of learning ability	The analysis identifies pupils' initial learning ability
Teaching Process and Methods	Teaching process design	The lesson sequence follows a coherent inquiry process
	Diversity of teaching methods	Methods are varied where appropriate (e.g., demonstration, experiment, discussion, or simulation)
	Student participation	The plan provides opportunities for pupils to exchange and discuss ideas autonomously
Problem and Situation Design	Effectiveness of problem design	Questions guide inquiry and elicit substantive thinking
	Relevance of situation creation	Situations connect with pupils' experience and support conceptual understanding
	Authenticity of situations	Situations are authentic or near-authentic and create opportunities for transfer
Thinking Cultivation Activities	Analytical thinking	Observation and comparison tasks are used to develop analytical thinking
	Evaluative thinking	Evaluation and discussion tasks are used to develop evaluative thinking
	Creative thinking	Independent explanation or design tasks are used to develop creative thinking
Resource and Technology Application	Integration of teaching resources	Textbooks, experimental materials, and other resources are purposefully integrated
	Application of educational technology	Educational technologies are used selectively in support of the learning goals

AHP was selected because the dimensions are related but do not necessarily contribute equally to the overall judgment. Pairwise comparison allows respondents to express relative importance more directly than assigning six independent scores. The method also provides a consistency statistic, which can identify comparisons that contradict one another. In the present study, each teacher compared the first-level indicators using the same ratio scale. The calculations converted these judgments into normalized weights. The consistency test concerns the logical coherence of a respondent's comparisons; it does not, by itself, establish the validity of the indicators or the representativeness of the final weights. Those questions require broader expert review and empirical testing.

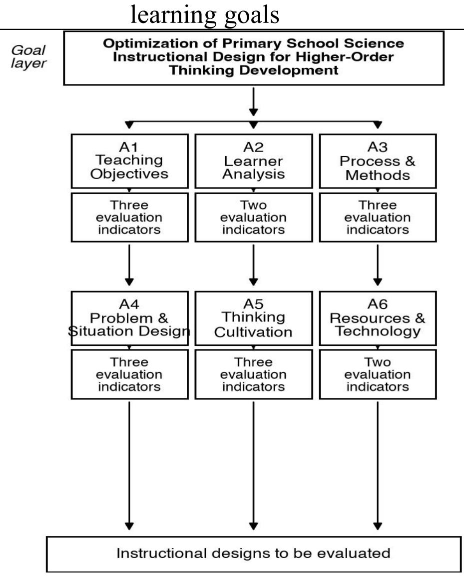

Figure 1. Hierarchical Structure Model of Instructional Design Evaluation

4.3 Consistency Testing Based on the Analytic Hierarchy Process

The analytic hierarchy process (AHP) was used to examine the relative importance of the indicators and the consistency of the judgments [10]. The procedure involved defining the hierarchy, constructing pairwise judgment matrices, calculating weights, and testing matrix consistency.

(1) Establishing the hierarchy. The criteria and sub-criteria identified through the review were arranged according to their relationships in the model shown in Figure 1.

(2) Constructing the pairwise judgment matrix. Pairwise comparisons were made using the 1–9 ratio scale. Three frontline science teachers completed the comparisons. Table 2 gives the matrix derived from one teacher's responses as an example.

Table 2. Judgment Matrix of the First-Level Indicators of Primary School Science Instructional Design Oriented toward Higher-Order Thinking Cultivation (One Teacher)

Indicator	Teaching Objectives	Learner Analysis	Process and Methods	Problem and Situation Design	Thinking Cultivation Activities	Resource and Technology Application
Teaching Objectives	1	3	1	1	1	2
Learner Analysis	0.333	1	1	3	1	5
Process and Methods	1	1	1	3	1	5
Problem and Situation Design	1	0.333	0.333	1	1	1
Thinking Cultivation Activities	1	1	1	1	1	5
Resource and Technology Application	0.5	0.2	0.2	1	0.2	1

(3) Calculating the weight vector. The matrix was analyzed with the AHP function of an online SPSS data-analysis platform. For this teacher, the weights of the six first-level indicators were 0.21404, 0.19968, 0.22267, 0.11273, 0.18934, and 0.06155 (Table 3).

Table 3. AHP Analysis Results

Item	Eigenvector	Weight (%)	Maximum Eigenvalue	CI
Teaching Objectives	1.284	21.404	6.601	0.12
Learner Analysis	1.198	19.968		
Process and Methods	1.336	22.267		
Problem and Situation Design	0.676	11.273		
Thinking Cultivation Activities	1.136	18.934		
Resource and Technology Application	0.369	6.155		

(4) Testing consistency. A judgment matrix is considered acceptably consistent when CR < 0.1. Here, the maximum eigenvalue was 6.601 and RI was 1.25, giving CR = CI/RI = 0.096 (Table 4). The matrix therefore met the consistency criterion.

Table 4. Consistency Test Results

Maximum Eigenvalue	CI	RI	CR	Consistency Test Result
6.601	0.12	1.25	0.096	Passed

4.4 Determination of the Final Weights of the Instructional Design Evaluation

The same procedure was applied to the other two teachers' responses, after which the three sets of weights were averaged. The final weights were 0.2477 for teaching objectives, 0.1643 for learner analysis, 0.2003 for teaching process and methods, 0.1763 for problem and situation design, 0.1657 for thinking cultivation activities, and 0.0458 for resource and technology application. The resulting order was A1 > A3 > A4 > A5 > A2 > A6. Teaching objectives received the greatest weight, followed by process and methods. Resources and technology received the smallest weight, suggesting that the participating teachers viewed them as supportive rather than central to higher-order thinking. Given the small consultation group, these figures should be treated as exploratory estimates rather than stable population weights.

4.5 Interpretation and Use of the Evaluation Framework

The weighting pattern suggests that the participating teachers regarded the pedagogical logic of a plan as more important than the technical means used to present it. Teaching objectives, process and methods, and problem and situation design together account for most of the total weight. This ordering is plausible because these dimensions determine what pupils are expected to think about and how they will engage with it. The comparatively low weight for resources and technology should not be read as evidence that materials are unimportant. A well-chosen model, specimen, or digital simulation may make an otherwise inaccessible phenomenon available for inquiry. The result instead indicates that a resource has value only in relation to the task and objective it supports; novelty or sophistication is not an educational end in itself.

The relative positions of learner analysis and thinking cultivation activities also merit attention. Both received substantial but lower weights than teaching objectives. Yet weak learner analysis can undermine every later stage of a plan. A task that demands evaluation may be unproductive if pupils lack the concepts, language, or experience needed to compare claims. Similarly, naming an activity as analytical or creative does not ensure that it elicits the intended thinking. Reviewers should therefore use the weights to organize an overall judgment, not to ignore a low-weight dimension. A serious weakness in any dimension may disrupt alignment across the design. Future validation should examine whether minimum standards or non-compensatory rules are needed alongside a weighted total score.

In practice, the framework can support both self-review and collaborative planning. Before a lesson, a teacher can examine each criterion and mark the part of the plan that provides evidence for it. A missing or weakly supported criterion then becomes a prompt for revision. During collaborative planning, two teachers can rate the same plan independently and discuss the reasons for any disagreement. Such discussion may be more useful than the numerical result itself because it makes tacit assumptions about learners, inquiry, and assessment visible. For novice teachers, worked examples could illustrate what weak, adequate, and strong evidence looks like for each indicator. For experienced teachers, the framework may serve as a compact checklist when adapting an existing plan to a new class.

The framework could also be used formatively across the planning, teaching, and reflection cycle. The pre-lesson rating identifies intended opportunities for higher-order thinking. Classroom observation and samples of pupil work can then show which opportunities were actually taken up. After the lesson, the teacher can compare the planned sequence with what occurred and revise the design accordingly. This comparison should not be treated as a performance appraisal unless the instrument has undergone much stronger validation. At its present stage, the framework is better suited to professional learning: it provides a language for discussing design decisions and for tracing how changes in a plan may affect pupils' opportunities to reason.

5. Establishing an Evaluation Mechanism for Higher-Order Thinking

The framework above evaluates planned instruction, but a strong lesson plan does not by itself show that pupils' thinking has developed. Evidence must also be gathered during and after classroom activity. Because primary science teachers currently have few practical tools for doing so, this section identifies four considerations for a future higher-order thinking evaluation mechanism.

Evaluation should give pupils an active role. In addition to teacher assessment, self- and peer assessment can prompt pupils to compare solutions, explain preferences, and identify the strengths and weaknesses of an argument [3].

The content of evaluation should extend beyond factual accuracy to the quality of pupils' reasoning. Observable behaviors might include noticing relevant features, comparing evidence, identifying patterns, explaining a relationship, generalizing from results, or abstracting a principle. The evidence selected should match the type of thinking targeted by the lesson.

No single method will capture this range of performance. Teachers might combine brief rating scales with field notes, pupils' written or visual products, recordings of group explanations, and reflective self-assessments. Evidence collected across several lessons is more informative than a one-off judgment because changes in thinking are gradual and context dependent.

Analytical, evaluative, and creative thinking provide three possible dimensions for organizing this evidence. The relevant indicators and expected level of performance should be specified for the particular task and age group.

A future scoring system should describe performance levels rather than rely only on yes-or-no decisions. For example, a problem-design indicator might distinguish among questions that ask for recall, questions that require an explanation based on evidence, and sequences that invite pupils to compare explanations and revise their ideas. Similar anchors could be written for each indicator and accompanied by examples from primary science topics. Pilot raters would then apply the rubric to a varied set of lesson plans. Agreement among raters, internal structure, and relationships with classroom observations and pupil work could provide evidence about reliability and validity. This process would turn the present conceptual framework into a more dependable practical instrument.

6. Limitations and Reflections

This study offers an initial index for reviewing primary science lesson plans intended to foster higher-order thinking. Its limitations define the scope of that contribution. First, the indicators were derived from literature and curriculum requirements rather than a formal content-validation study. Because little work directly addresses the evaluation of primary science instructional design, frameworks from related science subjects, including chemistry, were adapted. The author's limited teaching experience may also have affected the selection and wording of indicators. Second, only three frontline teachers provided pairwise judgments. This sample is too small to establish stable weights or examine variation among respondents, and no subject experts participated. The weights should therefore be treated as provisional. Future research should refine the indicators through Delphi consultation and test the weighting structure with a larger and more diverse sample. Third, the framework does not yet include performance levels, scoring anchors, or a complete rating form. Developing and testing these operational features is necessary before the index can be used for dependable assessment in schools.

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