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From Curriculum Reform to Sustainable Implementation: A Four-Condition Framework for Inquiry-Based Science Education in Greek Primary Schools

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ABSTRACT: The recent reform of the Greek primary science curriculum has repositioned inquiry-based learning (IBL) as a central organizing principle of science teaching from Grades 1 to 6. Although the curriculum formally promotes a shift from transmissive instruction to student-centered inquiry, the long-term success of this reform depends not only on curricular design but also on the systemic conditions that support classroom implementation. This article examines how IBL is operationalized in the new Greek primary science curriculum and analyzes the conditions required for its sustained enactment beyond pilot and experimental contexts. Drawing on curriculum documents, policy texts, and existing empirical and theoretical studies on Greek primary science education, the article develops a four-condition framework for sustainable IBL implementation: teachers' epistemological preparation, assessment alignment, institutional mediation through experimental model schools, and pedagogically meaningful integration of digital inquiry. The analysis suggests that the curriculum's inquiry-oriented ambitions exceed the current level of teacher preparedness and remain constrained by summative assessment traditions, uneven infrastructure, and the risk of using digital tools as substitutes rather than supports for authentic inquiry. The article argues that the reform represents an important epistemological advance in Greek science education, but its effectiveness will depend on coherent professional development, assessment reform, institutional support, and careful integration of digital technologies within the inquiry cycle.

KEYWORDS: Inquiry-based learning; primary science education; science curriculum; teacher professional development; Greece.

1. INTRODUCTION

Inquiry-based learning (IBL) has become one of the central principles of contemporary science education because it redefines learning as active participation in the epistemic practices of science rather than as the passive reception of established knowledge (National Research Council, 2012; Osborne, 2014; Pedaste et al., 2015). In primary science education, inquiry involves asking questions, observing phenomena, designing investigations, interpreting evidence, constructing explanations, and communicating conclusions. This orientation is particularly important in the early years of schooling, where pupils' first systematic encounters with science can shape their understanding of what scientific knowledge is and how it is produced. Contemporary research therefore does not treat inquiry merely as a teaching technique, but as a broader pedagogical and epistemological framework for developing conceptual understanding, scientific reasoning, and scientific literacy (Furtak et al., 2012; Lazonder & Harmsen, 2016).

The recent reform of the Greek primary science curriculum places Greece within this broader international movement toward competence-based and inquiry-oriented science education. The new curriculum formally positions inquiry-based learning as a central organizing principle of science teaching from Grades 1 to 6, following the enactment of the new curriculum through Official Government Gazette 3056/2023 and its preceding pilot implementation in Experimental Model Schools (Kotsis et al., 2025). It promotes a transition from textbook-centered and transmissive teaching toward learning environments in which pupils observe, question, investigate, reason from evidence, and communicate their findings (Gavrilas & Kotsis, 2025; Kotsis et al., 2023). In this respect, the reform represents an important epistemological shift in Greek primary science education, because it attempts to redefine the role of the teacher, the role of the learner, and the nature of school science itself.

Earlier work examined the conceptualization and integration of inquiry-based learning in the latest Greek primary science curriculum and identified both its promise and its emerging challenges (Kotsis, 2025a). That analysis emphasized the curriculum's movement from transmissive pedagogy toward student-centered inquiry, while also noting important tensions related to teacher preparation, assessment practices, resource inequalities, and the integration of digital and AI-enhanced inquiry. The present article builds on that discussion but adopts a different analytical focus. Rather than asking only how inquiry is represented in the curriculum, it examines the conditions under which inquiry-based learning can be sustained in everyday classroom practice beyond pilot or experimental contexts.

This distinction is necessary because curriculum reform does not automatically lead to pedagogical transformation. International research on inquiry-based science education shows that implementation gaps frequently emerge when ambitious curriculum texts are introduced into systems where assessment practices, teacher preparation, classroom resources, and institutional support remain unchanged (Strat et al., 2024). A curriculum may describe inquiry as a central principle, but teachers may still experience uncertainty about how to guide open-ended investigations, how to manage time and classroom interaction, how to assess inquiry processes, and how to balance student autonomy with conceptual guidance (Lazonder & Harmsen, 2016; Strat et al., 2024). These difficulties are especially important in centralized and examination-oriented education systems, where classroom practice is often shaped by long-standing traditions of content coverage, textbook dependence, and summative evaluation (OECD, 2020; Koulaidis & Dimopoulos, 2022).

In the Greek context, the implementation of inquiry-based learning is therefore not only a pedagogical question but also a systemic one. The reform requires teachers to act as designers of investigative learning environments, facilitators of scientific dialogue, and mediators of evidence-based reasoning. At the same time, it requires assessment practices that value process, argumentation, reflection, and inquiry competences rather than only factual recall (Harlen, 2015). It also requires schools to have sufficient institutional support, laboratory and digital resources, and opportunities for sustained professional development. Existing Greek evidence indicates that these conditions cannot be assumed, since pre-service primary teachers often show uneven scientific literacy, limited confidence in physics teaching, and naïve or incomplete views of scientific inquiry (Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Stylos, Siarka, & Kotsis, 2023; Tsoumanis, Stylos, & Kotsis, 2023).

The present article addresses this problem by analyzing the systemic conditions required for sustained inquiry-based science education in Greek primary schools. It focuses on three guiding questions. First, how does the new Greek primary science curriculum operationalize inquiry-based learning in relation to contemporary models of the inquiry cycle, particularly the five-phase model proposed by Pedaste et al. (2015)? Second, what does the available empirical evidence on Greek primary and pre-service teachers suggest about their readiness to enact inquiry-based science teaching? Third, what systemic conditions distinguish formal curriculum compliance from meaningful and sustainable implementation?

To answer these questions, the article develops a four-condition framework for sustained IBL implementation. The first condition is teachers' epistemological preparation, referring to their understanding of science as a process of inquiry, evidence, argumentation, and revision. The second condition is assessment alignment, because inquiry-based learning requires formative and process-oriented assessment practices that correspond to the aims of the curriculum (Harlen, 2015). The third condition is institutional mediation, especially through Experimental Model Schools and university-school partnerships that can support the transition from policy to classroom practice (Kotsis & Tsiouri, 2024; Kotsis et al., 2025). The fourth condition is pedagogically integrated digital inquiry, which treats digital tools, simulations, virtual laboratories, and AI-supported resources as supports for inquiry rather than as substitutes for students' own reasoning and experimentation (Evangelou & Kotsis, 2019; Gavrilas & Kotsis, 2025; Panagou, Stylos, & Kotsis, 2025).

The article therefore contributes to the discussion of Greek curriculum reform by shifting the focus from curriculum design to curriculum sustainability. Its central argument is that the new Greek primary science curriculum represents a significant step toward inquiry-oriented science education, but its success depends on the interaction of teacher preparation, assessment reform, institutional support, and careful digital integration. Inquiry-based learning can become a transformative practice in Greek primary science education only if these conditions are addressed coherently and not as isolated policy requirements.

2. METHODS

This article employs a critical literature review combined with document analysis of the current Greek primary science curriculum. The critical review approach was selected because the object of analysis is not a mature empirical intervention with a sufficiently large outcome literature, but a recently enacted national curriculum reform whose implementation is still developing. For this reason, the purpose of the article is not to calculate the effectiveness of inquiry-based learning through statistical aggregation, but to interpret how the reform is structured, how it relates to existing empirical evidence, and what systemic conditions are required for its sustained implementation. A critical review is appropriate for this purpose because it allows policy documents, curriculum texts, theoretical models, empirical studies, and prior conceptual analyses to be examined together under a common analytical framework (Grant & Booth, 2009).

The study builds on earlier published work that examined the conceptualization and integration of inquiry-based learning in the latest Greek primary science curriculum (Kotsis, 2025b). That earlier analysis identified the curriculum's epistemological movement from transmissive pedagogy toward student-centered scientific inquiry and highlighted emerging challenges related to teacher preparation, assessment, resource inequalities, and digital or AI-enhanced inquiry. The present article does not repeat that descriptive and conceptual analysis. Instead, it extends it by asking how inquiry-based learning can be sustained beyond curriculum discourse and pilot implementation. In this sense, the earlier study functions as a point of departure, while the present article develops a more explicit implementation-oriented framework.

The corpus of analysis consisted of three categories of sources. The first category included policy and curricular documents directly related to the Greek primary science curriculum. The central document was the Official Government Gazette of the Hellenic Republic, OGG 3056/2023, through which the new primary science curriculum was formally established and introduced for the 2024–2025 school year. Supporting documents included the curriculum design rationale, the pilot implementation report, and broader policy texts that situate the reform within Greek and European discussions of digital, green, and competence-based education (OECD, 2020; European Commission, 2022; Kotsis, Gikopoulou, Patrinopoulos, Kapotis, & Kalkanis, 2023; Kotsis et al., 2025).

The second category consisted of empirical studies on Greek primary science education, pre-service primary teachers, science teaching self-efficacy, scientific literacy, experimental teaching, and inquiry-related pedagogical practices. These studies were included because they provide evidence about the professional and institutional conditions under which the new curriculum is likely to be enacted. Particular attention was given to studies reporting findings on teachers' views of scientific inquiry, confidence in teaching physics and science, conceptual understanding, and classroom barriers to experimental or inquiry-based teaching (Evangelou & Kotsis, 2019; Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Stylos, Siarka, & Kotsis, 2023; Tsoumanis, Stylos, & Kotsis, 2023).

The third category included international theoretical, methodological, and review literature on inquiry-based learning. These sources were used to define the analytical criteria through which the Greek curriculum was examined. The analysis was informed by Pedaste et al.'s (2015) five-phase model of inquiry-based learning, Banchi and Bell's (2008) typology of inquiry openness, Furtak et al.'s (2012) meta-analysis of inquiry-based science teaching, Lazonder and Harmsen's (2016) meta-analysis on guidance in inquiry learning, and Strat et al.'s (2024) systematic review of inquiry-based science education in teacher education. Classical theoretical sources, including Dewey, Piaget, and Vygotsky, were retained as conceptual background but were not treated as sufficient empirical evidence for claims about contemporary classroom implementation.

The analysis proceeded in three stages. First, the new Greek primary science curriculum was examined in relation to Pedaste et al.'s (2015) inquiry cycle, with attention to the phases of orientation, conceptualization, investigation, conclusion, and discussion. This stage focused on whether each phase is explicitly operationalized in the curriculum or left mainly to teacher interpretation. Second, the curriculum was examined through the lens of inquiry openness, using Banchi and Bell's (2008) distinction among confirmation, structured, guided, and open inquiry. This made it possible to identify whether the curriculum mainly promotes structured, guided, or open forms of inquiry and whether these forms are appropriate for primary pupils. Third, the empirical and policy literature was synthesized around four implementation conditions: teachers' epistemological preparation, assessment alignment, institutional mediation, and digital-inquiry integration.

These four conditions were selected because they correspond to the main implementation tensions identified in both the Greek and international literature. Teachers' epistemological preparation concerns whether teachers understand inquiry as more than hands-on activity and are able to guide pupils toward evidence-based reasoning. Assessment alignment concerns whether classroom evaluation can capture inquiry processes, argumentation, interpretation, and reflection rather than only factual recall. Institutional mediation concerns the role of Experimental Model Schools, university-school partnerships, and professional learning networks in translating curriculum policy into classroom practice. Digital-inquiry integration concerns whether simulations, virtual laboratories, AI-assisted platforms, and other digital tools are used to support inquiry rather than replace pupils' own experimentation and reasoning.

The analysis is therefore interpretive, synthetic, and framework-building rather than experimental. Its aim is to clarify the conditions under which the Greek IBL reform may become sustainable across the primary school system. As such, the article does not claim to provide direct measurement of student outcomes after the full national implementation of the curriculum. Instead, it identifies the structural and pedagogical conditions that should guide future empirical evaluation. This limitation is important because the reform is recent and the available evidence remains uneven. However, by combining curriculum analysis, prior conceptual work, empirical findings from Greek primary science education, and international inquiry-based learning literature, the article provides a structured basis for evaluating the medium-term trajectory of the reform.

3. THEORETICAL FOUNDATIONS OF INQUIRY-BASED LEARNING

Inquiry-based learning is grounded in the view that science education should introduce learners not only to scientific concepts but also to the ways in which scientific knowledge is constructed, justified, revised, and communicated. In this sense, inquiry is not simply a classroom technique or a sequence of practical activities. It is an epistemological orientation that treats pupils as participants in scientific reasoning, even at the primary school level. This distinction is important for the Greek curriculum reform, because the challenge is not only to include more experiments or activities in science lessons, but to cultivate pupils' capacity to ask investigable questions, examine evidence, construct explanations, and discuss the reliability of their conclusions (National Research Council, 2012; Osborne, 2014; Pedaste et al., 2015).

The theoretical basis of inquiry-based learning may be understood through three complementary traditions. The first is the constructivist tradition, according to which learners actively construct knowledge rather than receive it passively. Piaget's theory of cognitive development emphasized that children build understanding through processes of assimilation and accommodation, while later conceptual-change research showed that science learning often requires pupils to reorganize prior ideas in response to evidence and explanation (Piaget, 1970; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 1994; Vosniadou & Skopeliti, 2014). From this perspective, inquiry is valuable because it creates opportunities for pupils to encounter phenomena, compare predictions with observations, and reconsider initial explanations. However, constructivism does not imply that pupils should simply be left to discover scientific ideas independently. Especially in primary education, inquiry requires careful guidance so that pupils' observations and interpretations can lead toward conceptual understanding rather than confusion or reinforcement of misconceptions (Lazonder & Harmsen, 2016).

The second tradition is the sociocultural view of learning, which emphasizes that scientific understanding develops through language, interaction, tools, and participation in shared practices. Vygotsky's theory of mediated learning and the Zone of Proximal Development provides a basis for understanding inquiry as a guided and collaborative activity rather than as an individual process of discovery (Vygotsky, 1978). In science classrooms, pupils learn to reason scientifically through dialogue, argumentation, explanation, and peer critique. This means that inquiry should include not only observation and experimentation but also structured opportunities for pupils to formulate claims, support them with evidence, respond to alternative interpretations, and revise their thinking through discussion (Mercer & Howe, 2012; Osborne, 2010; Erduran, Ozdem, & Park, 2015; Henderson, MacPherson, Osborne, & Wild, 2015). This point is particularly relevant to curriculum implementation, because teachers must be prepared to manage classroom discourse as part of inquiry, not only practical work.

The third tradition is the contemporary view of science as a set of epistemic practices. This approach moves beyond the idea that science education should focus mainly on scientific facts or even on a general "scientific method." Instead, it emphasizes the practices through which scientific communities produce and evaluate knowledge: asking questions, developing and using models, planning investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and communicating information (Duschl, 2008; Ford, 2008; National Research Council, 2012). Within this perspective, inquiry-based learning becomes a way of inducting pupils into the practices of science in age-appropriate forms. The Greek primary science curriculum's emphasis on pupils as active investigators is consistent with this view, but its classroom realization depends on whether teachers can transform inquiry from procedural activity into epistemic engagement.

Operational models of inquiry are useful because they translate these theoretical assumptions into classroom sequences. Pedaste et al. (2015) proposed a widely used five-phase model consisting of orientation, conceptualization, investigation, conclusion, and discussion. The orientation phase introduces pupils to a phenomenon or problem and stimulates curiosity. The conceptualization phase involves formulating questions or hypotheses. The investigation phase includes exploration, experimentation, data collection, and analysis. The conclusion phase requires pupils to connect evidence with explanations. The discussion phase involves communication, reflection, argumentation, and evaluation of inquiry processes and outcomes. This model is especially useful for analyzing curriculum documents because it allows the researcher to identify whether inquiry is fully operationalized or whether some phases are underdeveloped.

The degree of openness in inquiry is also central to its pedagogical effectiveness. Banchi and Bell (2008) distinguish among confirmation inquiry, structured inquiry, guided inquiry, and open inquiry. In confirmation inquiry, pupils verify a known result through a prescribed procedure. In structured inquiry, the teacher provides the question and procedure, while pupils generate explanations from the evidence. In guided inquiry, the teacher provides the question, but pupils design aspects of the investigation. In open inquiry, pupils formulate the question and design the investigation themselves. This distinction is important because primary pupils usually need substantial scaffolding. The evidence does not support the assumption that more open inquiry is always more effective. Instead, guided and structured inquiry are often more appropriate for younger learners, especially when the goal is conceptual understanding and epistemic development rather than unstructured exploration (Banchi & Bell, 2008; Lazonder & Harmsen, 2016).

The international literature therefore suggests that inquiry-based learning is most effective when it combines student activity with explicit guidance. Furtak et al. (2012) showed that inquiry-based science teaching can have positive effects on learning, while Lazonder and Harmsen (2016) emphasized that these effects depend strongly on the type and quality of guidance provided. This finding is important for the Greek reform because curriculum language that promotes inquiry must be accompanied by concrete support for teachers. Without guidance, inquiry may become a superficial sequence of activities; with excessive control, it may return to traditional teacher-led demonstration. Sustainable implementation requires a balance between pupil autonomy and pedagogical structure.

Epistemic cognition is another key dimension of inquiry-based learning. Inquiry should help pupils understand not only what scientists know but also how scientific knowledge is justified. This involves developing awareness of evidence, uncertainty, model-based reasoning, explanation, and the revisable character of scientific knowledge (Hofer & Pintrich, 1997; Sandoval, 2005; Chinn, Buckland, & Samarapungavan, 2011). At the primary level, this does not mean teaching abstract philosophy of science. It means helping pupils recognize that observations must be interpreted, that explanations require evidence, that different claims can be compared, and that conclusions may change when new evidence appears. This epistemic dimension is essential if inquiry is to contribute to scientific literacy rather than merely to practical classroom engagement.

These theoretical considerations have direct implications for teacher education and curriculum implementation in Greece. If inquiry is understood only as hands-on activity, teachers may focus on experiments without helping pupils develop evidence-based reasoning. If inquiry is understood only as student autonomy, teachers may under-scaffold learning and leave pupils without sufficient conceptual support. If inquiry is understood only as a curriculum requirement, it may become a formal procedure rather than a meaningful change in science teaching. Therefore, teachers need epistemological preparation, pedagogical content knowledge, and confidence in managing inquiry-oriented classroom discourse (Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Strat et al., 2024).

The theoretical foundation of this article therefore supports the four-condition framework developed later. Constructivist theory highlights the need for guided conceptual development. Sociocultural theory highlights the importance of dialogue, argumentation, and collaborative meaning-making. The epistemic-practices perspective highlights the need to treat science as a process of evidence-based knowledge construction. Operational models of inquiry highlight the importance of sequencing and scaffolding. Together, these perspectives show that the sustainability of inquiry-based learning depends not only on curriculum design but also on teacher preparation, assessment alignment, institutional mediation, and the careful integration of digital tools into the inquiry process. This is the analytical basis for examining the Greek primary science curriculum not simply as a policy text, but as a reform whose success depends on the conditions that make inquiry possible in everyday classrooms.

4. IMPLEMENTATION OF INQUIRY-BASED LEARNING IN THE GREEK PRIMARY SCHOOL CURRICULUM

The implementation of inquiry-based learning in the new Greek primary science curriculum represents a significant attempt to move from curriculum rhetoric to structured pedagogical practice. Unlike earlier reforms, in which inquiry was often mentioned as one possible teaching approach, the new curriculum places inquiry at the center of science teaching and learning. Its main innovation is that scientific knowledge is not presented only as content to be transmitted, but as knowledge that pupils gradually construct through observation, questioning, investigation, interpretation, and communication. This orientation distinguishes the new curriculum from more traditional textbook-centered models and aligns it with contemporary views of science as an epistemic and social practice (National Research Council, 2012; Osborne, 2014; Pedaste et al., 2015).

A useful way to examine the curriculum is to map its structure against the inquiry cycle proposed by Pedaste et al. (2015), which includes orientation, conceptualization, investigation, conclusion, and discussion. The orientation phase is strongly represented in the curriculum through activities that begin with phenomena, everyday experiences, problems, or questions intended to stimulate pupils' curiosity. This is pedagogically important because primary pupils often enter science lessons with intuitive explanations derived from daily experience. By beginning with observable phenomena rather than abstract definitions, the curriculum creates opportunities for pupils to activate prior knowledge, express initial ideas, and recognize the need for explanation.

The conceptualization phase is also present, although it is developed unevenly across grade levels. In the upper primary grades, pupils are expected to formulate questions, propose hypotheses, and recognize relationships among variables. These expectations are consistent with guided inquiry, where the teacher supports pupils in moving from curiosity to investigable questions. In the lower grades, however, conceptualization remains more implicit and depends heavily on teacher mediation. This is not necessarily a weakness, because younger pupils require considerable scaffolding; however, it means that the quality of implementation will depend strongly on the teacher's ability to transform pupils' spontaneous questions into scientifically meaningful inquiry (Banchi & Bell, 2008; Lazonder & Harmsen, 2016).

The investigation phase is the most visible and operationalized part of the curriculum. Pupils are encouraged to observe, classify, measure, compare, use simple instruments, conduct experiments, collect data, and work collaboratively. This emphasis is appropriate for primary science because practical engagement can support conceptual understanding when it is carefully structured. However, practical work alone does not guarantee inquiry-based learning. A classroom activity becomes inquiry-oriented only when pupils use evidence to answer questions, compare explanations, and reflect on the reliability of their conclusions. Therefore, the investigation phase must be connected to conceptualization, conclusion, and discussion; otherwise, inquiry risks being reduced to hands-on activity without epistemic depth (Furtak et al., 2012; Lazonder & Harmsen, 2016).

The conclusion phase requires pupils to interpret their findings and connect evidence with scientific explanations. This is one of the most demanding aspects of inquiry-based learning, especially in primary education. Pupils may observe a phenomenon correctly but still interpret it through naïve or incomplete conceptual frameworks. For this reason, the teacher's role remains essential. The curriculum's emphasis on evidence-based conclusions is valuable, but it also requires teachers to support pupils in distinguishing observation from inference, evidence from opinion, and explanation from description. In this respect, the curriculum's success depends not only on the presence of inquiry activities but also on teachers' pedagogical content knowledge and epistemological awareness (Harlen, 2015; Stylos, Christonasis, & Kotsis, 2023; Strat et al., 2024).

The discussion phase is the least secure element of implementation. Although the curriculum encourages communication, collaboration, and reflection, it gives less detailed guidance on how pupils should engage in argumentation, peer critique, and evaluation of competing explanations. This is important because discussion is not an optional extension of inquiry; it is the phase in which pupils learn to justify claims, listen to alternative interpretations, revise conclusions, and understand science as a collective knowledge-building process. International research has shown that argumentation and classroom discourse are central to scientific reasoning and epistemic cognition (Osborne, 2010; Mercer & Howe, 2012; Erduran, Ozdem, & Park, 2015; Henderson, MacPherson, Osborne, & Wild, 2015). Therefore, the curriculum would be strengthened by more explicit guidance on the organization of inquiry-based discussion, including teacher prompts, peer-response routines, and criteria for evidence-based argument.

The curriculum mainly promotes structured and guided inquiry rather than fully open inquiry. This is an appropriate choice for primary education. Fully open inquiry, in which pupils independently formulate questions and design investigations, can be valuable in selected contexts, especially in the upper grades, but it is not always suitable as the dominant model for young learners. Research indicates that inquiry is more effective when pupils receive appropriate guidance, particularly when they are still developing scientific concepts, procedural skills, and epistemic understanding (Banchi & Bell, 2008; Lazonder & Harmsen, 2016). The Greek curriculum's emphasis on guided inquiry is therefore pedagogically defensible, provided that guidance does not become excessive control and that pupils retain meaningful opportunities to make decisions, interpret evidence, and communicate explanations.

A further important feature of the curriculum is its effort to connect inquiry with interdisciplinary and socio-scientific themes. Science learning is linked to environmental issues, health, sustainability, technology, and everyday life. This broadens the meaning of inquiry beyond isolated experiments and helps pupils understand science as relevant to personal and social decision-making. Such an orientation is consistent with contemporary approaches to scientific literacy, which emphasize the ability to use scientific knowledge and evidence in real-world contexts (Osborne, 2014; Kyle, 2020; Zeidler, 2014). In the Greek context, this is especially important because inquiry-based learning can support not only conceptual understanding but also responsible citizenship, environmental awareness, and critical engagement with technological change.

The curriculum also gives increased attention to digital technologies, simulations, virtual laboratories, and STEM or STEAM-oriented activities. These tools can support inquiry by making invisible processes visible, enabling repeated experimentation, providing access to data, and helping pupils explore phenomena that cannot easily be investigated in the classroom. However, digital inquiry must be pedagogically integrated rather than treated as a substitute for direct observation and physical experimentation. Evidence from Greek primary science education suggests that real experimental activity can produce stronger conceptual gains than virtual simulation alone in some contexts (Evangelou & Kotsis, 2019). Therefore, the most productive approach is not to replace hands-on inquiry with digital tools, but to combine physical experimentation, simulation, modeling, and discussion in ways that deepen understanding.

Compared with previous Greek primary science curricula, the new curriculum is more ambitious in at least six dimensions. First, it frames science more explicitly as an epistemic practice rather than only as a body of knowledge. Second, it places inquiry at the center of science teaching rather than presenting it as an optional method. Third, it gives greater importance to formative and process-oriented assessment. Fourth, it integrates digital tools more directly into science learning. Fifth, it assigns teachers a more active role as designers and facilitators of inquiry environments. Sixth, it uses Experimental Model Schools and university-school partnerships as mediating structures for implementation. These changes indicate that the reform is not merely a change in content but an attempt to transform the culture of primary science education. Table 1 situates these changes within a broader comparative analysis, contrasting the 2024 curriculum with its two predecessors along the dimensions most relevant to inquiry-based reform.

Table 1. Comparison of the three most recent Greek primary science curricula along six dimensions relevant to inquiry-based learning.

Dimension	2003 Cross-Thematic Framework (DEPPS)	2011 "New School" Curriculum	2024 Inquiry-Based Curriculum (OGG 3056/2023)
Epistemological framing	Science as an organized body of knowledge to be transmitted, with limited references to constructivist learning; nature of science largely implicit.	Constructivist orientation introduced explicitly; science framed as both content and process, with influence from European competence frameworks.	Science framed as an epistemic practice; inquiry positioned as both method and object of learning; explicit alignment with contemporary nature-of-science perspectives.
Role of inquiry	Inquiry mentioned as one of several teaching approaches; in practice subordinated to content coverage and textbook sequence.	Inquiry foregrounded conceptually through project-based and experiential activities, but operational guidance limited; implementation depended heavily on individual teacher initiative.	Inquiry operationalized as the organizing principle, with structured pedagogical sequences corresponding to the phases of orientation, conceptualization, investigation, conclusion, and discussion (Pedaste et al., 2015).
Assessment model	Predominantly summative; written examinations and factual recall; minimal formative provision.	Formative assessment introduced in policy text but not operationalized through aligned instruments; summative culture remained dominant in practice.	Formative, process-oriented assessment mandated, including rubrics, portfolios, and self-assessment; alignment between curriculum and assessment articulated but contingent on teacher capacity.
Digital integration	Information and Communication Technology treated as a separate cross-thematic strand; digital tools peripheral to science instruction.	Digital tools introduced as supports for project work; uneven infrastructure across schools limited systematic uptake.	Digital tools, simulations, and virtual laboratories positioned as constitutive of inquiry rather than supplementary; STEM and STEAM/STREAM integration explicit (Gavrilas & Kotsis, 2025).
Teacher autonomy and role	Teacher as deliverer of mandated content; limited curricular flexibility; textbook-driven sequencing.	Teacher framed as facilitator in policy text, but textbook centrality and assessment culture constrained the role in practice.	Teacher framed as designer of inquiry environments and co-constructor of knowledge; greater curricular flexibility paired with elevated demands on pedagogical content knowledge and epistemological awareness.
Implementation infrastructure	National rollout without dedicated mediating institutions; teacher training delivered through standard in-service seminars.	Piloted in approximately 800 schools under ESPA funding; scaling interrupted by the 2010–2018 economic crisis and discontinuity of program leadership.	Two-year pilot in Experimental Model Schools, which serve as mediating institutions for the national rollout; explicit linkage between universities, IEP, and school networks (Kotsis & Tsiouri, 2024).

Note. DEPPS = Διαθεματικό Ενιαίο Πλαίσιο Προγραμμάτων Σπουδών; ESPA = Εταιρικό Σύμφωνο για το Πλαίσιο Ανάπτυξης (Partnership Agreement for the Development Framework); IEP = Institute of Educational Policy; OGG = Official Government Gazette.

At the same time, the curriculum contains important implementation risks. It assumes that teachers can guide inquiry, manage classroom dialogue, assess process-oriented learning, use digital tools critically, and adapt activities to diverse learners. These are demanding professional tasks. Existing evidence on Greek pre-service teachers shows that many future primary teachers have limited confidence in teaching science, especially physics, and may hold incomplete views of scientific inquiry (Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Stylos, Siarka, & Kotsis, 2023; Tsoumanis, Stylos, & Kotsis, 2023). This evidence suggests that the curriculum's ambitions may exceed the current level of teacher preparation unless systematic professional development is provided.

The implementation of inquiry-based learning in the Greek primary science curriculum should therefore be understood as a promising but conditional reform. The curriculum provides a stronger inquiry-oriented framework than previous approaches, especially through its emphasis on observation, investigation, evidence, communication, and digital support. However, the most demanding phases of inquiry, conceptualization, conclusion, and discussion, depend heavily on teacher expertise and assessment alignment. The reform's success will therefore be determined not

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simply by whether inquiry appears in the curriculum, but by whether teachers, schools, and assessment systems can support inquiry as a sustained classroom practice. This issue provides the basis for the next section, which examines the main challenges and opportunities for the future of inquiry-based science education in Greece.

5. CHALLENGES AND OPPORTUNITIES FOR THE FUTURE OF INQUIRY-BASED SCIENCE EDUCATION IN GREECE

The implementation of inquiry-based science education in Greece depends on whether the new curriculum can move beyond formal policy adoption and become a stable classroom practice. The previous section showed that the 2024 curriculum is more coherent and ambitious than earlier reforms because it places inquiry at the center of science teaching, links it with digital and STEM-oriented learning, and attempts to support implementation through Experimental Model Schools and university-school partnerships. However, the transition from curriculum design to sustainable enactment remains challenging. The central issue is not whether inquiry-based learning is desirable, but whether the Greek primary education system can provide the professional, institutional, and assessment conditions required for its meaningful use in everyday classrooms (Kotsis, 2025b; Kotsis et al., 2025; Strat et al., 2024).

The first and most important condition is teachers' epistemological preparation. Inquiry-based learning requires teachers to understand science not only as a body of established knowledge but also as a process of questioning, investigation, evidence evaluation, argumentation, and revision. This epistemological shift is demanding because many teachers have themselves been educated within systems that emphasize correct answers, textbook knowledge, and teacher authority. In such contexts, inquiry may easily be misunderstood as simple hands-on activity or as a loosely structured form of student autonomy. However, contemporary inquiry-based learning requires neither unstructured discovery nor mechanical experimentation. It requires teachers who can guide pupils from curiosity to investigable questions, from observation to explanation, and from individual ideas to evidence-based classroom discussion (Pedaste et al., 2015; Lazonder & Harmsen, 2016; Strat et al., 2024).

Greek empirical evidence suggests that this condition cannot be taken for granted. Studies of pre-service primary teachers indicate uneven scientific literacy, limited confidence in teaching physics, and incomplete understandings of scientific inquiry (Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Stylos, Siarka, & Kotsis, 2023; Tsoumanis, Stylos, & Kotsis, 2023). These findings are particularly important because primary teachers are expected to teach science across several domains, often without the disciplinary specialization of secondary science teachers. If teachers lack confidence in physics or hold naïve views of inquiry, they may avoid open questioning, over-rely on textbook explanations, or reduce inquiry to simple demonstrations. Therefore, the reform's success depends on systematic teacher education that combines scientific content knowledge, pedagogical content knowledge, and explicit reflection on the nature of scientific inquiry.

The main opportunity in this area is that the Greek teacher-education system can support coordinated reform if university departments, school networks, and curriculum authorities work together. Teacher preparation should include not only courses about inquiry-based learning but also repeated opportunities to design, teach, observe, and evaluate inquiry lessons. Pre-service and in-service teachers need experience in managing pupils' questions, scaffolding investigations, addressing misconceptions, and organizing evidence-based discussion. Short seminars are unlikely to be sufficient. International evidence suggests that professional development is more effective when it is sustained, practice-based, connected to classroom realities, and supported through mentoring or collaborative teacher communities (Loughran, 2019; Strat et al., 2024). For Greece, this means that inquiry-based learning should become a continuous professional development priority rather than a temporary reform slogan.

The second condition is assessment alignment. Inquiry-based learning cannot be sustained if assessment continues to reward mainly factual recall and reproduction of textbook content. The new curriculum promotes formative and process-oriented assessment, including portfolios, rubrics, self-assessment, peer assessment, and evaluation of inquiry competences. This direction is consistent with the logic of inquiry, because pupils should be assessed not only on what they know but also on how they ask questions, collect evidence, interpret data, construct explanations, and revise their thinking (Harlen, 2015; Kotsis et al., 2025). However, assessment reform is difficult because Greek education remains strongly influenced by summative traditions and by the broader culture of examination-oriented learning (OECD, 2020).

The difficulty is that teachers may support inquiry in principle but still feel pressure to produce measurable, easily graded outcomes. In this situation, inquiry activities may be used occasionally, while regular assessment continues to privilege written answers and factual knowledge. This creates a contradiction between curriculum aims and classroom incentives. If pupils and parents understand success mainly as the ability to reproduce correct answers, teachers may hesitate to devote time to open investigation, dialogue, or reflection. Assessment alignment is therefore not a technical issue but a cultural and systemic one. It requires assessment tools that are practical enough for everyday use but rich enough to capture inquiry processes.

The opportunity is to develop clear and usable assessment instruments for primary science inquiry. These instruments should help teachers evaluate pupils' ability to formulate questions, make predictions, design simple investigations, interpret evidence, work collaboratively, and communicate conclusions. Rubrics should not become bureaucratic checklists; they should support teacher judgment and pupil reflection. Portfolios can document the development of inquiry over time, while self-assessment can help pupils become aware of how their reasoning changes during investigation. Such tools would also help reduce the risk that inquiry remains invisible in assessment. Without aligned assessment, inquiry may be valued in curriculum discourse but marginalized in classroom practice (Harlen, 2015; Strat et al., 2024).

The third condition is institutional mediation. Curriculum reforms often fail when they move directly from central policy to classroom expectation without intermediate structures that support teachers in implementation. The role of Experimental Model Schools is therefore especially important in the Greek reform. These schools can function as laboratories of pedagogical innovation, places where inquiry sequences are tested, adapted, observed, and improved before wider dissemination. They can also create links among curriculum designers, university departments, school advisors, and classroom teachers. In this respect, they are not simply pilot schools; they are potential mediating institutions between national curriculum policy and local classroom practice (Kotsis & Tsiouri, 2024; Kotsis et al., 2025).

However, the mediating capacity of Experimental Model Schools has limits. Their number is small compared with the total number of primary schools in Greece, and their conditions are not always representative of ordinary schools. Teachers in non-experimental schools may face larger classes, fewer resources, weaker laboratory infrastructure, and fewer opportunities for collaboration. Therefore, the challenge is not only to produce good inquiry practices in Experimental Model Schools but to create mechanisms through which these practices can be transferred, adapted, and sustained in diverse school contexts. Dissemination events alone are insufficient. More durable forms of mediation are needed, such as mentoring networks, collaborative lesson design, teacher communities, and partnerships between experimental and non-experimental schools.

The opportunity is to use Experimental Model Schools as hubs for regional professional learning rather than as isolated examples of innovation. If these schools support ordinary schools through shared lesson materials, classroom observation, co-teaching, mentoring, and reflective workshops, they can help reduce the gap between reform policy and classroom practice. University departments can also contribute by connecting teacher education, research, and school-based implementation. This would make inquiry-based learning a shared professional project rather than an individual teacher responsibility. Such an approach is especially important in a centralized system where curriculum change can be mandated nationally but enacted only locally.

The fourth condition is digital-inquiry integration. The new curriculum gives an important role to digital tools, simulations, virtual laboratories, data platforms, and STEM or STEAM activities. These resources can enrich inquiry because they allow pupils to visualize invisible processes, repeat experiments, collect and represent data, and explore phenomena that may be difficult to observe directly in the classroom. Digital tools can also support inclusion by offering alternative modes of representation and participation. However, the pedagogical value of digital tools depends on how they are used. A simulation is not inquiry-based simply because it is interactive; it becomes inquiry-based only when pupils use it to ask questions, test ideas, analyze evidence, and discuss explanations (Gavrilas & Kotsis, 2025; Kotsis, 2024b; Panagou, Stylos, & Kotsis, 2025).

This distinction is crucial because digital tools may either deepen inquiry or weaken it. If they are used as substitutes for pupils' own reasoning, they can encourage passive manipulation or acceptance of ready-made explanations. If they are used to complement direct observation and physical experimentation, they can strengthen conceptual understanding. Greek evidence indicates that real experimental activity can produce stronger conceptual gains than virtual simulation alone in some contexts, suggesting that digital inquiry should be hybrid rather than substitutive (Evangelou & Kotsis, 2019). Therefore, the curriculum should not encourage a simple replacement of laboratory activity with digital simulations, especially in under-resourced schools. Instead, digital tools should be integrated into inquiry sequences in ways that prepare, extend, or deepen physical investigation.

The rise of artificial intelligence adds another layer to this challenge. AI-supported tools can assist pupils by generating questions, offering feedback, providing explanations, or supporting differentiated learning. They may also help teachers design inquiry tasks or adapt materials to pupils' needs. However, AI can also create epistemological risks if pupils accept generated answers without evaluation, confuse fluent explanation with reliable evidence, or reduce inquiry to interaction with a digital assistant. For this reason, AI-enhanced inquiry must include critical digital literacy. Pupils should learn to question AI-generated explanations, compare them with observations, and treat them as prompts for reasoning rather than as final authorities (Kotsis, 2024b; Panagou, Stylos, & Kotsis, 2025).

These four conditions are interdependent. Teachers cannot implement inquiry effectively without epistemological preparation, but even well-prepared teachers may be constrained by assessment systems that reward memorization. Assessment reform can support inquiry, but it requires institutional structures that help teachers design and use new tools. Experimental Model Schools can mediate implementation, but their influence depends on whether they are connected to broader professional networks. Digital tools can enrich inquiry, but only if teachers have the pedagogical knowledge to use them critically and if assessment practices value the reasoning that digital inquiry can support. Sustainable implementation therefore requires coherence across all four conditions.

The future of inquiry-based science education in Greece should therefore be approached as a systemic reform rather than as a change in classroom technique. The curriculum has created an important opportunity by formally repositioning science learning around inquiry, evidence, communication, and reflection. However, the reform will become meaningful only if teachers are supported, assessment is aligned, institutional mediation is expanded, and digital tools are integrated within inquiry rather than used as substitutes for it. The challenge is not simply to introduce inquiry-based activities into science lessons, but to build a professional and institutional culture in which inquiry becomes a normal way of teaching and learning science.

6. A FOUR-CONDITION FRAMEWORK FOR SUSTAINED INQUIRY-BASED REFORM

The analysis in the previous sections indicates that the sustainability of inquiry-based learning in Greek primary science education cannot be explained by one factor alone. The curriculum may be theoretically well designed, but implementation depends on the interaction of several conditions. Teacher preparation, assessment practice, institutional support, and digital integration do not operate separately. They influence one another and together determine whether inquiry becomes a sustained classroom culture or remains a formal curriculum requirement. For this reason, the present article proposes a Four-Condition Framework for sustained inquiry-based reform.

The framework develops the implementation issues identified in the Greek curriculum and in the wider literature on inquiry-based science education. Earlier analysis of the Greek curriculum showed that inquiry has been positioned as a fundamental principle of science education, but also that its enactment remains dependent on teacher development, assessment reform, adequate resources, and cultural support (Kotsis, 2025b). The present framework extends that discussion by organizing these issues into four interrelated conditions: epistemological preparation, assessment alignment, institutional mediation, and digital-inquiry integration. These conditions are not presented as optional recommendations. They are proposed as necessary elements of sustainable inquiry-based reform.

The first condition is epistemological preparation. Teachers must understand inquiry not only as practical activity but as a way of constructing and evaluating scientific knowledge. This includes understanding the role of questions, hypotheses, evidence, argumentation, uncertainty, and revision in science. Without this epistemological preparation, teachers may reduce inquiry to simple experiments, demonstrations, or loosely organized group work. Such practices may increase classroom activity but may not necessarily develop scientific reasoning. The Greek evidence on pre-service teachers' scientific literacy, inquiry views, and science teaching self-efficacy suggests that this condition requires systematic attention in teacher education and professional development (Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Stylos, Siarka, & Kotsis, 2023; Tsoumanis, Stylos, & Kotsis, 2023).

The second condition is assessment alignment. Inquiry-based learning requires assessment practices that recognize the processes of inquiry, not only the correctness of final answers. Pupils should be assessed on their ability to ask questions, make predictions, plan investigations, collect and interpret evidence, construct explanations, participate in discussion, and reflect on their learning. If assessment remains mainly summative and content-oriented, teachers will have limited incentive to devote time to open investigation and argumentation. The problem is therefore not only methodological but systemic. The curriculum may promote inquiry, but classroom practice will remain constrained if assessment continues to reward mainly memorization and factual reproduction (Harlen, 2015; OECD, 2020; Strat et al., 2024).

The third condition is institutional mediation. Curriculum reforms require structures that translate policy into classroom practice. In the Greek case, Experimental Model Schools and university-school partnerships can play this mediating role by testing inquiry sequences, supporting teacher learning, producing examples of practice, and creating feedback channels between schools and curriculum developers. This condition is especially important because sustainable reform cannot rely only on individual teacher motivation. It requires professional communities, mentoring, shared resources, and institutional continuity. The role of Experimental Model Schools is therefore central, but their influence must extend beyond pilot settings if inquiry-based learning is to become a national classroom practice (Kotsis & Tsiouri, 2024; Kotsis et al., 2025).

The fourth condition is digital-inquiry integration. Digital tools, simulations, virtual laboratories, AI-supported resources, and STEM-oriented platforms can support inquiry, but they do not automatically produce inquiry-based learning. Their value depends on whether they are integrated into the inquiry cycle in ways that support questioning, prediction, experimentation, evidence analysis, and explanation. If digital tools are used only for presentation or as substitutes for physical experimentation, their epistemic value is reduced. Greek evidence showing the importance of real experimental activity indicates that digital inquiry should be hybrid and complementary rather than substitutive (Evangelou & Kotsis, 2019). The same principle applies to AI-supported tools, which should support pupils' reasoning rather than replace it (Kotsis, 2024b; Panagou, Stylos, & Kotsis, 2025).

These four conditions are interdependent. A teacher may have a strong epistemological understanding of inquiry, but if assessment remains focused on factual recall, classroom practice may still return to traditional patterns. Assessment tools may be well designed, but without institutional support teachers may not have the confidence or time to use them. Experimental Model Schools may generate good practices, but these practices will not spread widely without professional networks and adaptation to ordinary school contexts. Digital tools may be available, but without teacher preparation they may be used superficially. The framework therefore argues that sustainable inquiry-based reform requires coordinated development across all four conditions.

Table 2. The Four-Condition Framework for Sustained Inquiry-Based Reform

Condition	Main meaning	Current implementation challenge	Required development
1.Epistemological preparation	Teachers understand science as inquiry, evidence, argumentation, and revision.	Many teachers may interpret inquiry as simple hands-on activity or may lack confidence in teaching science, especially physics.	Strengthened pre-service and in-service teacher education, with emphasis on scientific inquiry, nature of science, conceptual understanding, and classroom discourse.
2.Assessment alignment	Assessment evaluates inquiry processes as well as content knowledge.	Summative and content-oriented traditions may discourage sustained inquiry practice.	Development of practical rubrics, portfolios, formative feedback tools, self-assessment, and peer-assessment procedures for primary science inquiry.
3.Institutional mediation	Schools, universities, and professional networks support the movement from policy to practice.	Experimental Model Schools have strong potential but limited reach across the whole system.	Expansion of mentoring networks, school partnerships, collaborative lesson design, and dissemination mechanisms connecting experimental and ordinary schools.
4.Digital-inquiry integration	Digital tools support questioning, investigation, modeling, data interpretation, and explanation.	Simulations and AI tools may be used as substitutes for reasoning or physical experimentation.	Hybrid inquiry designs combining hands-on experiments, simulations, data tools, and critical digital literacy.

The framework shows that inquiry-based reform should not be evaluated only by the presence of inquiry terminology in curriculum documents. It should be evaluated by the degree to which these four conditions are simultaneously developed. A curriculum can be inquiry-oriented in language but weak in implementation if teachers are not prepared, assessment is misaligned, institutional support is limited, or digital tools are poorly integrated. Conversely, the reform becomes more sustainable when these conditions reinforce one another. For example, teacher professional development can include the design of assessment rubrics; Experimental Model Schools can model hybrid digital inquiry; university-school partnerships can support both epistemological preparation and classroom-based assessment innovation.

The Four-Condition Framework also helps distinguish between surface implementation and deep implementation. Surface implementation occurs when teachers adopt the visible forms of inquiry, such as experiments, group work, worksheets, or digital simulations, without changing the underlying epistemology of teaching and learning. Deep implementation occurs when pupils are consistently supported in asking questions, interpreting evidence, constructing explanations, engaging in discussion, and reflecting on how knowledge is justified. The difference between the two depends on the interaction of the four conditions. Inquiry becomes sustainable only when classroom practices, assessment expectations, institutional support, and digital tools all point toward the same pedagogical purpose.

In the Greek context, the framework suggests that the 2024 curriculum has created a promising foundation but not a completed reform. Its strongest contribution is that it formally repositions science learning around inquiry and gives institutional visibility to the need for new forms of teaching and assessment. Its main vulnerability is that the professional and institutional conditions required for inquiry are still developing. This means that the reform should be understood as a medium-term process rather than as a single curriculum event. The question is not only whether teachers use inquiry activities, but whether the system progressively builds the conditions that allow inquiry to become normal, assessable, supported, and intellectually meaningful.

The Four-Condition Framework therefore provides an analytical tool for future evaluation of the Greek reform. Researchers can use it to examine whether teachers' epistemological understanding improves over time, whether assessment practices become more inquiry-oriented, whether Experimental Model Schools effectively support wider professional learning, and whether digital tools are integrated as complements to physical and conceptual inquiry. Policymakers can use it to identify where support is weakest and where coordinated intervention is needed. Teacher educators can use it to redesign preparation programs around the actual demands of inquiry-based teaching. In this way, the framework connects curriculum analysis with future empirical research and practical reform planning.

The central argument of the framework is that sustained inquiry-based science education requires coherence. Inquiry cannot flourish if it is promoted in curriculum texts but contradicted by assessment, unsupported by institutions, or reduced to digital activity. It becomes sustainable only when teachers, pupils, schools, assessment systems, and technologies work within a shared understanding of science as evidence-based, dialogic, and revisable knowledge. This coherence is the main condition for transforming the Greek primary science curriculum from an ambitious policy document into a living classroom practice.

7. RESEARCH AGENDA FOR EVALUATING THE MEDIUM-TERM TRAJECTORY OF THE REFORM

The 2024 Greek primary science curriculum has created an important opportunity for the renewal of science education, but its real significance will depend on what happens after formal implementation. Curriculum documents can establish inquiry-based learning as an official priority, but they cannot by themselves determine how teachers interpret inquiry, how pupils experience it, how assessment practices change, or how schools support implementation. For this reason, the next phase of research should move beyond curriculum description and examine the medium-term trajectory of the reform in actual classroom conditions. Earlier work has already identified the conceptual promise and emerging challenges of inquiry-based learning in the new Greek curriculum (Kotsis, 2025b). The present article extends that discussion by proposing a four-condition framework, and this framework can guide future empirical investigation.

The first research priority concerns teachers' epistemological preparation. Future studies should examine whether pre-service and in-service teachers develop more sophisticated understandings of scientific inquiry after the introduction of the new curriculum. This includes their views about the nature of scientific knowledge, the role of evidence, the meaning of experimentation, the importance of argumentation, and the difference between hands-on activity and inquiry-based reasoning. Existing evidence indicates that many Greek pre-service primary teachers show incomplete views of scientific inquiry, uneven scientific literacy, and limited confidence in science teaching, especially in physics-related domains (Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Stylos, Siarka, & Kotsis, 2023; Tsoumanis, Stylos, & Kotsis, 2023). Future research should therefore investigate whether teacher education programs and professional development initiatives are changing these patterns over time.

A second research priority concerns classroom enactment. It is not enough to know whether teachers report positive attitudes toward inquiry-based learning. Research should examine how inquiry is actually enacted in classrooms. This requires classroom observation, lesson analysis, teacher interviews, and pupil work samples. Particular attention should be given to whether all phases of the inquiry cycle are implemented or whether teaching remains concentrated mainly on observation and practical activity. The discussion phase is especially important because it is where pupils justify claims, compare interpretations, and develop epistemic understanding. Future studies should therefore examine whether pupils are regularly supported in argumentation, evidence-based explanation, and reflection, or whether these elements remain secondary to activity completion (Pedaste et al., 2015; Osborne, 2010; Mercer & Howe, 2012; Strat et al., 2024).

A third research priority concerns assessment alignment. The new curriculum promotes formative and process-oriented assessment, but there is still a need to examine whether teachers use assessment tools that capture inquiry competences. Future studies should investigate the design and classroom use of rubrics, portfolios, self-assessment tools, peer-assessment procedures, and teacher feedback practices. Research should also examine how pupils understand assessment in inquiry-based science lessons. If pupils continue to believe that success in science means memorizing correct answers, then inquiry may remain superficial even when activities appear student-centered. Assessment research is therefore essential because it can show whether the curriculum's epistemological shift is reflected in the way learning is valued and documented (Harlen, 2015; OECD, 2020).

A fourth research priority concerns the role of Experimental Model Schools and institutional mediation. These schools have been central to the pilot implementation and may function as hubs for professional learning, lesson design, and dissemination. However, their capacity to influence the wider primary school system remains an empirical question. Future research should examine how practices developed in Experimental Model

Schools are transferred to ordinary schools, whether mentoring and collaboration networks are effective, and what kinds of support teachers in non-experimental schools actually receive. This research should also investigate whether regional differences, school resources, class size, and teacher experience affect the transferability of inquiry-based practices (Kotsis & Tsiouri, 2024; Kotsis et al., 2025).

A fifth research priority concerns digital-inquiry integration. The new curriculum places considerable emphasis on digital tools, simulations, virtual laboratories, and STEM or STEAM-oriented practices. However, future research should distinguish between superficial digital use and genuine digital inquiry. Studies should examine whether digital tools support pupils' questioning, investigation, data interpretation, modeling, and explanation, or whether they are used mainly for presentation and demonstration. Particular attention should be given to hybrid designs that combine physical experimentation with simulations and digital representations. Greek evidence suggests that real experimental activity can produce stronger conceptual gains than virtual simulation alone in some contexts, so future studies should examine how digital and physical inquiry can be combined most effectively (Evangelou & Kotsis, 2019; Gavrilas & Kotsis, 2025).

A sixth research priority concerns artificial intelligence in inquiry-based science education. AI-supported tools may help teachers design inquiry tasks, generate questions, provide feedback, or differentiate instruction. They may also support pupils by offering explanations, prompts, or alternative representations. However, AI may also weaken inquiry if pupils treat generated answers as authoritative or if teachers use AI to replace rather than stimulate reasoning. Future research should examine how AI tools are used in primary science classrooms, how pupils evaluate AI-generated information, and how teachers develop critical digital literacy within inquiry-based learning. This line of research is especially important because AI is increasingly present in education, but its epistemological implications for young learners remain insufficiently understood (Kotsis, 2024b; Panagou, Stylos, & Kotsis, 2025).

A seventh research priority concerns equity and inclusion. Inquiry-based learning has the potential to support diverse learners because it allows multiple forms of participation, including observation, drawing, discussion, manipulation of materials, data recording, and collaborative explanation. However, this potential is not automatically realized. Future studies should examine whether pupils with different learning needs, linguistic backgrounds, socio-economic conditions, and levels of prior science exposure benefit equally from inquiry-based science teaching. Research should also examine whether schools with fewer resources are able to implement inquiry at the same level as better-equipped schools. Without this evidence, there is a risk that inquiry-based reform may unintentionally widen educational inequalities.

An eighth research priority concerns pupil outcomes. Future studies should examine not only pupils' engagement but also their conceptual understanding, scientific reasoning, epistemic cognition, and attitudes toward science. Inquiry-based learning should not be evaluated only by whether pupils enjoy science lessons or participate actively. It should also be evaluated by whether pupils develop better explanations, use evidence more effectively, understand uncertainty, and become more capable of scientific reasoning. Longitudinal research would be especially valuable because inquiry-based learning may influence pupils' development over time rather than through immediate short-term gains alone (Furtak et al., 2012; Lazonder & Harmsen, 2016).

These research priorities suggest that the evaluation of the Greek reform should be multi-dimensional. A narrow evaluation based only on curriculum compliance or teacher self-report would not be sufficient. Instead, future research should combine document analysis, classroom observation, teacher interviews, pupil assessment, professional development evaluation, and comparative school studies. Such research would allow scholars and policymakers to determine whether inquiry-based learning is becoming a stable part of Greek primary science education or whether it remains mainly a reform discourse.

The Four-Condition Framework proposed in this article can serve as an organizing tool for this research agenda. Studies of teacher preparation can examine the first condition. Studies of formative assessment can examine the second condition. Studies of Experimental Model Schools and professional networks can examine the third condition. Studies of simulations, virtual laboratories, and AI-supported learning can examine the fourth condition. In this way, the framework is not only a theoretical contribution but also a guide for empirical evaluation.

The medium-term question is therefore not simply whether the new curriculum includes inquiry-based learning. It clearly does. The more important question is whether the Greek education system develops the conditions required to make inquiry-based learning intellectually meaningful, assessable, equitable, and sustainable. Answering this question will require systematic research over the coming years, with attention to teachers, pupils, schools, assessment practices, and digital environments. Only such research can determine whether the 2024 curriculum reform becomes a lasting transformation in Greek primary science education or another ambitious policy initiative whose classroom impact remains uneven.

8. CONCLUSION

The reform of the Greek primary science curriculum represents an important moment in the development of science education in Greece. By positioning inquiry-based learning as a central organizing principle, the curriculum moves beyond the traditional view of science as a fixed body of knowledge to be transmitted by the teacher. It presents science learning as a process of observation, questioning, investigation, interpretation, evidence-based explanation, and communication. This shift is consistent with contemporary international understandings of inquiry-based science education and with the broader movement toward scientific literacy, competence-based learning, and active pupil participation (National Research Council, 2012; Osborne, 2014; Pedaste et al., 2015).

However, the significance of the reform cannot be judged only by the ambition of the curriculum text. The main question is whether inquiry-based learning can become a sustained classroom practice across Greek primary schools. Earlier analysis has shown that the new curriculum introduces a promising epistemological and pedagogical shift, but also that its implementation is challenged by teacher preparation, assessment practices, resource inequalities, and digital or AI-related uncertainties (Kotsis, 2025b). The present article has extended that discussion by arguing that the sustainability of the reform depends on four interrelated conditions: teachers' epistemological preparation, assessment alignment, institutional mediation, and pedagogically meaningful digital-inquiry integration.

The first condition, teachers' epistemological preparation, is fundamental because inquiry-based learning cannot be implemented effectively if teachers understand inquiry only as practical activity or occasional experimentation. Teachers need to understand science as a process of evidence construction, argumentation, explanation, and revision. They also need the pedagogical confidence to guide pupils through uncertainty without either controlling every step or leaving them unsupported. Existing Greek evidence on pre-service primary teachers' scientific literacy, science teaching self-efficacy, and views of scientific inquiry suggests that this condition requires systematic attention in both pre-service and in-service teacher education (Stylos, Christonasis, & Kotsis, 2023; Stylos, Kamtsios, & Kotsis, 2023; Stylos, Siarka, & Kotsis, 2023; Tsoumanis, Stylos, & Kotsis, 2023).

The second condition, assessment alignment, is equally important. Inquiry-based learning requires forms of assessment that value questioning, investigation, interpretation, discussion, and reflection. If assessment remains mainly summative and content-oriented, teachers and pupils will continue to prioritize factual recall, even when the curriculum promotes inquiry. The new curriculum's emphasis on formative and process-oriented assessment is therefore essential, but it must be supported by practical tools such as rubrics, portfolios, self-assessment procedures, peer assessment, and teacher feedback strategies. Without such alignment, inquiry risks becoming an attractive pedagogical language rather than a regular and assessable classroom practice (Harlen, 2015; OECD, 2020; Strat et al., 2024).

The third condition, institutional mediation, concerns the structures that support the movement from policy to practice. Experimental Model Schools and university-school partnerships can play a crucial role in this process because they can test inquiry sequences, support professional learning, generate examples of practice, and connect curriculum development with classroom realities. However, their influence must extend beyond pilot contexts. If inquiry-based learning remains concentrated in experimental or better-supported schools, the reform will not become system-wide. Sustainable implementation therefore requires networks of collaboration, mentoring, lesson design, classroom observation, and adaptation across diverse school contexts (Kotsis & Tsiouri, 2024; Kotsis et al., 2025).

The fourth condition, digital-inquiry integration, is increasingly important in contemporary science education. Digital tools, simulations, virtual laboratories, data platforms, and AI-supported resources can enrich inquiry by expanding what pupils can observe, model, and investigate. Nevertheless, digital tools do not automatically produce inquiry. They must be integrated into the inquiry cycle in ways that support pupils' questions, predictions, evidence analysis, explanations, and critical reflection. Greek evidence suggests that real experimental activity remains important and that virtual simulations should complement rather than replace physical investigation (Evangelou & Kotsis, 2019). Similarly, AI-supported tools should be used to stimulate reasoning and critical evaluation, not to replace pupils' own thinking (Kotsis, 2024b; Panagou, Stylos, & Kotsis, 2025).

The Four-Condition Framework proposed in this article helps distinguish between formal adoption and deep implementation. Formal adoption occurs when inquiry appears in curriculum documents, lesson plans, or classroom activities. Deep implementation occurs when inquiry changes the way pupils learn science, the way teachers guide learning, the way assessment values reasoning, and the way schools support pedagogical innovation. The Greek curriculum has created the possibility of such deep implementation, but this possibility depends on whether the four conditions develop coherently and simultaneously.

The article also shows that the new curriculum should be understood as a medium-term reform process rather than as a completed policy event. Its success will not be determined only by the official introduction of new curriculum documents, but by the gradual development of teacher expertise, assessment culture, institutional support, and critical digital practice. Future research should therefore examine how inquiry is enacted in classrooms, how teachers' views and practices change over time, how pupils develop inquiry competences, how assessment tools are used, and how Experimental Model Schools contribute to broader professional learning.

In conclusion, the new Greek primary science curriculum marks a significant step toward inquiry-oriented science education. Its greatest strength is that it redefines science learning as an active, evidence-based, dialogic, and reflective process. Its main vulnerability is that the conditions required for this transformation are still unevenly developed. Inquiry-based learning will become sustainable only if it is supported not merely as a curriculum principle but as a coherent educational culture. For Greek primary science education, the challenge now is to transform inquiry from an official reform aspiration into a normal, meaningful, and equitable classroom practice.

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