

Science at the margins: Curriculum mapping of science education in Greek primary teacher preparation

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ABSTRACT

This study examines the structure and implementation of science education in the curricula of Greek departments of primary education (DPEs) for the academic year 2024-2025, contextualizing the findings within an international comparative framework. The research conducted a rigorous curriculum mapping of all nine DPEs, examining both the officially intended and the delivered science-related courses, with an emphasis on their disciplinary orientation, pedagogical characteristics, compulsory status, and positioning within study programs. The research revealed significant discrepancies between the intended and implemented curricula, with numerous scheduled courses unavailable. Physics predominated in the disciplinary profile, whereas chemistry, biology, and inquiry-based or laboratory courses were underrepresented. The majority of scientific courses were theoretical, elective, and focused on the initial semesters, indicating a disjointed and peripheral role of scientific education in teacher training. These findings align with global research highlighting ongoing difficulties in establishing cohesive, inquiry-based science teacher education programs. The study indicates that comprehensive change is essential to guarantee curricular consistency, mandatory core science courses, and practical learning opportunities across the program. These modifications would enhance pre-service teachers' scientific literacy, pedagogical confidence, and preparedness to facilitate inquiry-based learning in primary classrooms. The Greek situation offers significant insights for the international dialogue on curriculum development and educator proficiency in science education.

Keywords: science education, science curriculum, teacher education, scientific literacy, inquiry-based learning

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INTRODUCTION

Science and technology are becoming increasingly integral to social, environmental, and economic decision-making, whereas elementary education is essential for establishing the foundations of scientific literacy from an early age. Modern definitions of scientific literacy highlight the importance of both subject-specific knowledge and the ability to critically engage with societal concerns, reason based on evidence, and partake in democratic discussions regarding science-related matters (Norambuena-Meléndez et al., 2023). In this context, primary science curricula must equilibrate conceptual comprehension, inquiry, and practical engagement, alongside fostering attitudes and values that promote enduring interest in science. Recent comparison and review studies indicate that actual curricula frequently fail to meet these aspirations and exhibit significant variation in structure and

emphasis across different nations (Deehan et al., 2024; Silva et al., 2023; Tsiouri et al., 2024).

The quality of science education in primary classrooms is closely associated with educators' preparation and continuous professional development. Research indicates that numerous pre-service primary educators commence university with inadequate science content knowledge, minimal experience in inquiry-based methodologies, and diminished confidence in science instruction, all of which may hinder their subsequent classroom practices (Antink-Meyer et al., 2023; Tsoumanis et al., 2024). Empirical evidence from the Greek context further demonstrates that pre-service primary teachers often exhibit limited levels of scientific literacy, raising concerns about their readiness to design and implement inquiry-oriented science instruction (Stylos et al., 2023b). Notably, comparative research indicates that in some cases the scientific literacy levels of pre-service teachers do not substantially exceed those of primary school students, underscoring the depth of the challenge facing teacher education programs (Tsoumanis

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et al., 2023). Systematic reviews of primary science interventions have underscored that student-centered methodologies, including inquiry-based learning, problem-based learning, and integrated STEM activities, generally yield beneficial outcomes for students' knowledge, skills, and attitudes. However, these reviews also stress the necessity for teachers to possess robust pedagogical content knowledge (PCK) and consistent curricular support to implement these approaches effectively (Almonacid-Fierro et al., 2023; Deehan et al., 2024; Rodríguez et al., 2024).

These advances have stimulated a growing scholarly interest in the framing of science and STEM within curriculum materials and teacher education programs. Comparative curriculum analyses reveal that, even within seemingly analogous policy frameworks, significant disparities exist in the articulation of goals, content strands, and levels of inquiry, as well as in the emphasis placed on scientific literacy as a primary outcome (Norambuena-Meléndez et al., 2023; Silva et al., 2023; Tsiouri et al., 2024). Recent comparative analyses focusing specifically on Greek teacher education curricula further indicate considerable variation in the treatment of environmental and science-related education across Greek departments of primary education (DPEs), highlighting fragmentation and lack of coherence in program design (Tsiouri et al., 2025). For instance, cross-national examinations of primary science curricula indicate that certain systems prioritize disciplinary coherence and cumulative progression, while others emphasize broad thematic or environmental approaches, with assessment regimes either bolstering or undermining ambitious curricular objectives (Silva et al., 2023; Tsiouri et al., 2024). This research highlights that the curriculum is not a neutral backdrop but a significant structuring element influencing teachers' capabilities in the classroom.

Although there is an increasing amount of comparative research on school-level scientific curriculum, the curricula of teacher education programs have garnered relatively little systematic scrutiny. Current evaluations have primarily concentrated on particular aspects, such as PCK in science teacher education, the development of STEM-oriented programs, or specific pedagogical innovations (Almonacid-Fierro et al., 2023; Ribeirinha & Correia, 2025; Rodríguez et al., 2024). These studies offer significant insights into how specialized courses or interventions can enhance the comprehension of teaching and learning science; yet they seldom delineate the comprehensive structure of the curriculum that pre-service primary teachers experience during their entire degree program. Uncertainties persist regarding the quantity of science-related courses available, the specific scientific fields they encompass, the degree of integration of content, pedagogy, and practical practice, and the extent to which they are mandatory or optional within comprehensive study programs.

Recent empirical research demonstrates the significance of these inquiries. Investigations into pre-service teachers' motivation and beliefs regarding science reveal that personal interest and perceived relevance are influenced by both individual factors and the nature of experiences provided in university scientific courses (Tsoumanis et al., 2024). Research on pre-service teachers' scientific curiosity and confidence in teaching specific subjects indicates that thoughtfully crafted course experiences, which include genuine inquiry tasks and chances to relate science to everyday contexts, can enhance their readiness to participate in science instruction (Antink-Meyer et al., 2023). Interventions employing new pedagogies, such as flipped classroom models in science methods courses, have been shown to

improve pre-service teachers' science teaching self-efficacy and attitudes, contingent upon their integration within coherent program frameworks (Ribeirinha & Correia, 2025). Without a definitive understanding of the foundational structure of science in teacher education curriculum, it is challenging to assess the representativeness of such interventions in relation to standard pre-service experiences.

Increasing data suggests that the leadership and prominence of elementary science in schools are partially contingent upon the extent to which teachers have been equipped to assume responsibility for the subject. Research on professional learning in primary science demonstrates that persistent, subject-specific development opportunities can enhance teachers' confidence in leading science and contribute to overall school success (Markwick & Reiss, 2024). Nevertheless, if beginning teacher education offers merely a disjointed or insufficient science preparation, educators may commence their careers lacking a robust foundation for subsequent professional development. Consequently, from a global standpoint, it is imperative to comprehend how various national systems structure scientific education in primary teacher training and how these organizational decisions may influence discrepancies in classroom practices and student outcomes.

The Greek background presents a notably intriguing case for this research. In Greece, primary teachers receive their education in university DPEs, which possess a certain degree of autonomy in curriculum design while adhering to national regulatory frameworks. In the context of wider European initiatives to improve STEM education and promote scientific literacy, Greek departments confront the difficulty of reconciling disciplinary depth, pedagogical training, and the development of inquiry-based, student-centered methodologies in science. Recent research on European scientific curricula indicates that there is no singular, standardized model for organizing science education across the continent, resulting in significantly divergent pathways for both students and educators due to national policy decisions (Tsiouri et al., 2024).

This study examines the structure of science education in the curricula of DPEs for the academic year 2024-2025, within the wider international context. It analyzes the science courses officially cataloged in study guides and juxtaposes them with the courses provided to students, recording essential characteristics such as course type, scientific discipline, pedagogical approach, semester of offering, and designation as compulsory or elective. This study seeks to elucidate commonalities and notable discrepancies in the positioning of science education within beginning teacher preparation by systematically mapping the curriculum across all nine DPEs. This national case is analyzed in conjunction with international research on primary scientific curricula and teacher education, aiming to contribute to comparative discussions and enlighten debates regarding curriculum reform in Greece and abroad.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The conceptualization of science education in teacher preparation programs has progressed in tandem with broader changes in curriculum theory and educational policy. In the last twenty years, worldwide publications and comparative studies have highlighted the importance of scientific literacy as a fundamental objective of

compulsory education and a crucial skill for democratic engagement in a knowledge-driven society (OECD, 2023; Roberts & Bybee, 2014). Scientific literacy is now broadly seen as comprising not only content knowledge but also an epistemic comprehension of scientific processes, the capacity to apply scientific reasoning to quotidian contexts, and the inclination to critically and morally interact with sociocentric issues. These views have profoundly influenced the framing of science within teacher education curriculum, particularly for primary-level educators who must reconcile disciplinary knowledge with developmentally suitable pedagogy (Strat et al., 2024).

From a curriculum theory standpoint, science education in teacher preparation may be analyzed through two interrelated perspectives: the framework of knowledge and the approach to pedagogy. Shulman's (1986) notion of PCK remains fundamental in this context. PCK denotes the distinctive amalgamation of content knowledge and pedagogical strategies that educators utilize to render subject matter intelligible to students. In the realm of science, this encompasses a thorough comprehension of scientific principles as well as an awareness of prevalent misconceptions, investigative methodologies, and representations that enhance student comprehension. Empirical studies in science teacher education have shown that pre-service primary teachers frequently hold robust alternative conceptions and display fragmented reasoning in core scientific domains, such as thermal phenomena, even when encountered in everyday contexts (Stefanou et al., 2024). Rather than being viewed merely as errors, such alternative ideas have been shown to constitute a valuable pedagogical resource that can be systematically leveraged to promote conceptual change and deeper scientific understanding (Kotsis, 2023). Recent advancements, such as the technological pedagogical content knowledge model, have expanded this paradigm to incorporate the digital technologies that increasingly pervade scientific inquiry and educational practice (Mishra et al., 2023). These theoretical perspectives underscore that proficient science instruction necessitates not only subject matter expertise but also the synthesis of knowledge domains within cohesive curricular experiences.

Investigations of worldwide scientific teacher education indicate both similarities and differences in the manifestation of these concepts within curriculum. Numerous systems have embraced an inquiry-based approach, consistent with constructivist perspectives on learning that prioritize active student involvement in sense-making and experimentation (Lederman et al., 2013). European Commission (2020) and OECD (2023) initiatives of the early 2010s robustly endorsed inquiry-based science education (IBSE), evidencing that genuine inquiry experiences improve student motivation and conceptual comprehension when educators are sufficiently prepared (Rocard et al., 2007). Empirical research in the Greek context indicates that pre-service primary teachers often hold partial, fragmented, or procedural views of scientific inquiry, frequently equating it with simple activity-based teaching rather than with authentic epistemic practices (Stylos et al., 2023a). Nonetheless, research underscores the ongoing difficulties educators encounter in executing IBSE, including restricted curricular time, assessment limitations, and a lack of trust in conducting open-ended inquiries (Setiyani et al., 2025). The challenges frequently originate from the design of pre-service programs, where inquiry is occasionally presented as a theoretical concept rather than as an experiential pedagogical practice (Windschitl et al., 2012).

Comparative curriculum analyses have revealed significant patterns in the distribution of science material within primary teacher education. Certain national programs employ a discipline-based framework, featuring separate courses in physics, chemistry, and biology, whilst others utilize an integrated or theme methodology that connects science to environmental or technological contexts (Silva et al., 2023; Tsiouri et al., 2024). Integrated models are frequently defended on educational grounds, corresponding with the comprehensive nature of primary education; yet detractors contend that these methods may compromise conceptual rigor without robust progression frameworks (Voogt & Roblin, 2012). In contrast, discipline-specific courses may offer depth but pose the risk of compartmentalization and diminished applicability to classroom practice. The equilibrium between breadth and depth continues to be a fundamental challenge in curriculum design.

A pertinent area of research is the status and placement of science within teacher education programs in relation to other disciplines. Research from several European and non-European contexts demonstrates that science frequently holds a peripheral status in pre-service curriculum relative to reading, mathematics, and general pedagogy (Beudels et al., 2022; Wang et al., 2015). This marginalization is evident in reduced credit hours, elective rather than mandatory status, and restricted chances for practical experiences in science education. The result is a group of graduates who may not perceive science as essential to their professional identity. Resolving this challenge necessitates both curriculum reform and institutional dedication, alongside financial allocation, to enhance the prominence of science in teacher education.

Moreover, global studies underscore that successful curricular frameworks in science teacher education must delineate explicit learning outcomes encompassing cognitive, emotive, and practical dimensions. The framework established by National Research Council (2012) and the next generation science standards (NGSS Lead States, 2013) posits that three-dimensional learning, encompassing disciplinary core ideas, crosscutting concepts, and scientific practices, should guide school curricula and teacher training. Recent research utilizing this framework in pre-service contexts indicates that programs incorporating these characteristics can enhance comprehension of the nature of science and facilitate pedagogical preparedness for inquiry-based instruction (Papadouris et al., 2025; Zhang et al., 2022). The findings indicate that curriculum congruence between university and school levels is crucial for the ongoing enhancement of science education quality.

In this theoretical framework, curriculum mapping has surfaced as an effective analytical and developmental instrument. Mapping enables researchers and institutions to visualize the alignment of courses with overarching program aims, detect redundancies or gaps, and assure comprehensive coverage of topic and pedagogy (Harden, 2001). In the context of science education, curriculum mapping can determine if programs facilitate a coherent advancement of scientific comprehension and pedagogical proficiency or if experiences are disjointed and inconsistent. This strategy has been employed in comparative studies to examine national teacher training patterns and to evaluate reforms against international benchmarks (Paz & Locatelli, 2023). Synthesizing the above perspectives, this study conceptualizes science education in primary teacher preparation as a dynamic intersection of scientific literacy, PCK, inquiry-based learning, and

curriculum coherence. Scientific literacy provides the overarching societal and civic rationale, emphasizing not only knowledge of scientific concepts but also epistemic understanding, critical reasoning, and engagement with socio-scientific issues. PCK operationalizes this vision at the level of teaching practice, highlighting the necessity for future teachers to integrate disciplinary understanding with knowledge of learners, representations, and instructional strategies. Inquiry-based learning functions as the primary pedagogical vehicle through which scientific literacy and PCK can be developed experientially, fostering epistemic agency, curiosity, and reasoning. Curriculum coherence, in turn, constitutes the structural condition that enables these elements to be meaningfully connected across time, courses, and learning experiences. From this perspective, the quality of science education in teacher preparation cannot be reduced to the presence of isolated courses but must be examined in terms of their alignment, sequencing, pedagogical orientation, and institutional status. This integrative framework guides the present curriculum mapping, which analyses not only the quantity of science-related offerings but also their disciplinary balance, pedagogical character, and positioning within the overall program structure.

From a curriculum theory standpoint, this study adopts a critical-analytic orientation that views curriculum not merely as a technical plan of instruction but as a socio-institutional construct that reflects educational priorities, power relations, and conceptions of knowledge. While technical-instrumental models emphasize alignment between objectives, content, and assessment, critical and interpretive traditions highlight the ways in which curricula privilege certain disciplines, forms of knowledge, and pedagogical approaches over others (Pinar, 2019). In teacher education, curriculum structure functions as a powerful signal of what counts as essential professional knowledge. The positioning of science as compulsory or elective, early or late, theoretical or experiential is therefore not pedagogically neutral but shapes teachers' professional identities, confidence, and instructional repertoires. By employing curriculum mapping as an analytical tool, the present study seeks not only to describe the distribution of science-related courses but also to interrogate the structural and epistemic status of science education within primary teacher preparation programs.

METHODOLOGY

This study employed a systematic curriculum mapping and comparative document analysis design to examine the organization, content, and positioning of science education in undergraduate programs of DPEs. The objective was to deliver an empirically based delineation of the representation of science-related courses in formal curricula, the comparative analysis of these offers across institutions, and their alignment with global trends in teacher education. This sort of curriculum analysis has been extensively utilized in educational research as a diagnostic and developmental instrument, especially for recognizing strengths, shortcomings, and inconsistencies in program design (Harden, 2001; Pinar, 2019). The study sought to clarify the extent to which science plays a cohesive and essential role in the training of future primary educators by considering curricula as both policy texts and reflections of institutional goals.

The study encompassed all nine DPEs functioning within Greek public institutions for the 2024-2025 academic year. These departments

comprise the full range of institutions tasked with training primary school teachers in Greece, thereby providing a comprehensive national perspective. The units of analysis comprised the officially published study guides [Οδηγοί Σπουδών], which delineate the structure, learning objectives, and course offerings for each program, along with the lists of courses actually delivered for the corresponding academic year as reported on the departments' websites and online student portals. This dual focus enabled the identification of disparities between planned curricula (as officially designed) and enacted curricula (as executed in reality), a distinction that is essential in curriculum studies (Goodlad et al., 1979; Remillard & Heck, 2014).

Data were gathered from June to September 2024. For each DPE, all courses that explicitly addressed one or more domains of the natural sciences (physics, chemistry, biology, earth sciences, astronomy, and geology), integrated science, or science education were identified and included in the analysis. In addition, courses in environmental education, sustainability, and geography were included only when their official descriptions indicated a substantial focus on scientific concepts, processes, or inquiry practices, rather than purely socio-political, cultural, or policy-oriented content. For example, environmental education modules emphasizing ecosystems, energy, climate processes, or human-environment interactions grounded in scientific reasoning were classified as science-related, whereas courses primarily addressing environmental ethics, citizenship, or educational policy were excluded. Similarly, geography courses were included when they focused on physical geography, earth systems, or geoscientific processes, and excluded when centered mainly on human geography or social studies perspectives. Courses in mathematics, technology, or educational psychology were excluded unless they contained explicit and substantive natural science components. These inclusion and exclusion decisions were guided by the conceptual criterion of epistemic relevance to scientific knowledge and practices, rather than by course titles alone, to ensure analytical consistency and transparency.

Each course was categorized along multiple analytical dimensions, generated iteratively from established curriculum analysis models (Caspersen et al., 2017; Paz & Locatelli, 2023), and modified through preliminary coding of two departments:

1. Course classification:
 - (a) general education/background,
 - (b) subject-specific (disciplinary) science,
 - (c) skill development (e.g., laboratory or fieldwork),
 - (d) didactics of science, or
 - (e) integrate.

This typology indicates the extent to which a course enhances understanding of the topic, pedagogical proficiency, or both.

2. Scientific domain: specifying the primary subject or amalgamation of disciplines involved (e.g., physics, chemistry, biology, earth sciences, integrated science, and environmental studies).
3. Nature of course delivery: predominantly theoretical, experimental/practical, or hybrid.
4. Course classification: mandatory, mandatory elective (from a designated group), elective, or freely selected.
5. Semester offered: determining its chronological position within the four-year curriculum (early, middle, or late stages).

6. Instructor scientific specialization was recorded for each course based on publicly available departmental profiles and curriculum vitae and categorized into three broad groups:
- (a) disciplinary scientists (e.g., physicists, biologists, chemists, and geoscientists),
 - (b) science education specialists, and
 - (c) faculty from other educational or social science fields.

This variable was included to explore potential relationships between instructor background and the pedagogical orientation of courses (e.g., theoretical vs. inquiry-based), as previous research suggests that disciplinary training may influence instructional emphasis and epistemic framing. Although not treated as an independent variable in a statistical sense, instructor specialization was used interpretively in the discussion to contextualize patterns of pedagogical approach and disciplinary representation.

Each course constituted an individual data point within a nationwide dataset. Frequency and distributions were computed for each dimension, and comparative tables were created to illustrate inter-departmental variation. Conceptual diagrams, reflecting the original Greek figures, were subsequently developed to encapsulate the primary trends:

- (a) discrepancies between designed and delivered courses,
- (b) equilibrium of disciplines within science education,
- (c) comparative ratios of theoretical to experimental courses,
- (d) distribution of compulsory vs. elective courses, and
- (e) patterns of semester allocation.

These representations, however, are primarily qualitative and enable the analysis of patterns that would be challenging to express only through language. A qualitative analysis of course descriptions was conducted alongside quantitative summaries to identify pedagogical approaches and thematic foci. Terms such as inquiry, experiment, observation, project-based, or environmental awareness were classified as indications of constructivist or experiential pedagogy. Courses that prioritize subject mastery, historical foundations, or conceptual overviews were classified as content-oriented. The coding was performed separately by two researchers, achieving an intercoder agreement greater than 0.90 (Cohen's κ), hence ensuring classification reliability (Armstrong & Towery, 2022).

The research did not involve human participants and used solely publicly accessible institutional materials, thereby mitigating ethical issues related to participant consent. To guarantee transparency and replicability, all data sources were stored with complete citations of institutional URLs and retrieval dates.

International frameworks and literature were used to provide a contextual comparison to interpret the findings. European Commission's (2020) recommendations for STEM teacher education, the OECD's (2023) reports on science and innovation education, and curriculum models from various countries (e.g., Portugal, England, Australia, and Singapore) functioned as benchmarks. This comparative approach enabled the Greek situation to be contextualized within broader trends of curricular organization and reform in worldwide science education.

The analytical process consequently integrated descriptive mapping with interpretive comparison. The method offered a comprehensive depiction of the conceptualization, prioritization, and implementation

of science education in Greek primary teacher education, without seeking statistical generalization. The subsequent section presents conclusions that consolidate the data into five thematic patterns, collectively illustrating the current status of science-related coursework in Greece and its correlation with international developments in the discipline.

Several limitations of the present study should be acknowledged. First, the analysis is based exclusively on publicly available institutional documents, including study guides, departmental websites, and online course listings. While these sources provide official representations of curricula, they may not fully capture variations in actual classroom practice, informal pedagogical adaptations, or the depth of inquiry implemented within individual courses.

Second, although the distinction between intended and implemented curricula was systematically addressed, the study does not include observational data, interviews with faculty, or student perspectives, which could offer richer insight into curriculum enactment. Third, the analysis is limited to a single academic year (2024-2025) and therefore cannot account for longitudinal changes or temporary fluctuations in course offerings due to staffing or administrative factors.

In addition, the present mapping does not systematically weight science-related courses by ECTS credits. In the Greek context, however, undergraduate courses in DPEs are typically assigned a uniform number of ECTS, irrespective of discipline or compulsory/elective status. For this reason, course counts constitute a reasonable proxy for the relative curricular weight of science education within the programs examined. Nevertheless, future cross-national studies, in which credit allocations may vary substantially across institutions, would benefit from incorporating ECTS-weighted analyses to further refine international comparisons.

Finally, decisions regarding the classification of courses, particularly in borderline cases such as environmental education or geography, inevitably involve some interpretive judgment, even though explicit criteria were applied to enhance transparency and consistency. These limitations do not undermine the value of the mapping exercise but should be considered when interpreting the findings and their generalizability.

RESULTS

The curriculum mapping of the nine DPEs revealed a diverse and often disjointed representation of the integration of science education into teacher preparation programs. In total, 54 science-related courses were identified across the nine departments in the officially intended curricula, of which 42 were actually delivered during the 2024-2025 academic year. Each individual course constituted a unit of analysis. The subsequent outcomes are presented with reference to five analytical dimensions:

- (a) discrepancies between intended and implemented curricula,
- (b) disciplinary distribution,
- (c) pedagogical orientation and mode of delivery,
- (d) compulsory vs. elective status, and
- (e) temporal positioning within the four-year study programs.

Table 1. Intended and implemented science courses in DPEs (2024-2025)

University	Intended courses (study guide)	Implemented courses (delivered)	Percentage delivered
Athens (EKPA)	10	7	70%
Aegean	6	5	83%
Crete	7	7	100%
Ioannina	9	6	67%
Patras	8	5	63%
Thessaloniki (ATh)	9	8	89%
Thessaly	8	6	75%
Thrace (DTh)	8	6	75%
Western Macedonia	7	4	57%

Table 2. Distribution of science education courses by scientific discipline in DPEs (2024-2025)

Scientific discipline	Number of courses	Percentage of total
Physics	20	37%
Natural science	13	24%
Environmental science/sustainability	9	17%
Biology	6	11%
Chemistry	4	7%
Earth sciences/geography/astronomy	2	4%

Table 3. Pedagogical nature and mode of delivery of science education courses in DPEs (2024-2025)

Course type	Description	n	PT
Theoretical (lecture-based)	Emphasis on conceptual understanding and disciplinary content; minimal practical component.	30	56%
Experimental/laboratory	Courses include structured experiments, demonstrations, or the use of laboratory facilities.	8	15%
Hybrid (theory + practice)	Integrated courses combining conceptual instruction with practical or project-based components.	10	19%
Inquiry-based/fieldwork	Courses are explicitly centered on inquiry, investigation, or outdoor science activities.	6	10%

Note. n: Number of courses & PT: Percentage of total

The primary finding concerns the discrepancy between the anticipated and the executed curriculum. **Table 1** indicates that each department officially listed several science-related courses in its curriculum; however, the number of courses offered during 2024-2025 was significantly reduced. On average, 25-30% of scheduled science courses were not provided across institutions.

This trend reveals discrepancies in curriculum implementation and potential deficiencies in qualified personnel or insufficient student enrollment in elective courses. Similar differences between design and execution have been observed across various national contexts, especially where institutional autonomy coexists with restricted control over curriculum delivery (Beudels et al., 2022). The Greek situation illustrates a comparable vulnerability in sustaining uniform delivery of science education within departments.

The second pattern pertains to the disciplinary structure of science education. **Table 2** illustrates the allocation of courses among scientific disciplines, with a distinct preponderance of physics and general integrated science modules. Conversely, chemistry, biology, and earth sciences are significantly underrepresented, with merely two departments providing independent chemistry courses and less than fifty percent incorporating a biology course. Environmental science is becoming prevalent, however it is often situated within transdisciplinary or sustainability contexts rather than recognized as a separate scientific discipline. This discrepancy corresponds with global assessments indicating that physics frequently eclipses other scientific disciplines in teacher education (Silva et al., 2023; Tsiouri et al., 2024). The outcome is a limited content profile that may restrict pre-service teachers' comprehension of science as a cohesive and diverse domain.

The third key trend encompasses pedagogical orientation and course delivery. **Table 3** indicates that theoretical courses predominate,

comprising over two-thirds of the offers. A limited handful of courses integrate experimental, inquiry-based, or field components, and even these are generally elective rather than mandatory. Only three disciplines incorporate laboratory sessions into mandatory courses, and the majority are demonstration-oriented rather than exploratory.

This finding aligns with studies indicating that pre-service programs globally continue to prioritize conceptual education over experiential involvement (Setiyani et al., 2025; Strat et al., 2024). Insufficient exposure to inquiry practices during training may impede future teachers' capacity to cultivate genuine investigation and reasoning in elementary classrooms.

The fourth dimension pertains to the organizational standing of science courses within curricula. **Table 4** demonstrates that fewer than one-third of all science-related courses are mandatory. The majority are classified as elective or restricted-choice categories, enabling students to fulfill their degree requirements with less exposure to science. In two departments, all scientific courses were optional. This marginal positioning aligns with worldwide research indicating that science often receives fewer credit hours and diminishes institutional significance than literacy or mathematics (Strat et al., 2024). The elective designation indirectly indicates that science is secondary to the development of professional identity in primary education, perpetuating cycles of diminished confidence and evasion.

Table 4. Status of science education courses in DPEs (2024-2025)

Course status	Description	N	PT	DOC
Compulsory	Required courses that all students must complete to graduate.	14	26%	7
Compulsory elective (restricted choice)	Courses chosen from a defined group within the program's requirements.	12	22%	5
Elective (open choice)	Optional courses selected freely by students within or outside science education.	24	44%	9
Freely chosen/independent study	Individually arranged research or project-based courses in science education.	4	8%	3

Note. n: Number of courses; PT: Percentage of total; & DOC: Departments offering courses in this category

Table 5. Temporal distribution of science education courses across four-year study programs in DPEs (2024-2025)

Program stage (semester range)	Description	n	PT	Typical course focus
Years 1-2 (semesters 1-4)	Foundational phase; emphasis on disciplinary science content and general education modules.	33	61%	Physics fundamentals, introduction to natural sciences, and environmental awareness.
Year 3 (semesters 5-6)	Intermediate phase: introduction to science pedagogy and selected laboratory or project-based modules.	13	24%	Science didactics, school-based experiments, and integrated STEM themes.
Year 4 (semesters 7-8)	Advanced phase: connection with practicum, curriculum design, and inquiry-based applications.	8	15%	Teaching practice, science education seminars, and research projects.

Note. n: Number of courses & PT: Percentage of total

Table 5 illustrates the temporal allocation of science courses during the four-year academic cycle. The predominance of courses in the first two years, accounting for roughly 60% of all offers, indicates that science is primarily viewed as foundational material rather than an ongoing educational theme. Only three departments provide science courses in the last year, during which practical experiences generally take place. This sequencing limits the integration of scientific understanding with pedagogical practice. Comparative research from Finland and Singapore demonstrates that the incremental distribution of science education courses across program years improves pedagogical understanding of the subject and the application of theory in classroom practice (Silva et al., 2023; Zhang et al., 2022).

In addition to these quantitative patterns, qualitative analysis of course descriptions indicated enduring traditional notions of teaching and learning. Terminology such as "presentation," "overview," or "fundamental concepts" was prevalent, whereas clear references to inquiry, experimentation, or problem-based learning were limited and mostly confined to science pedagogy or environmental modules. The disparity between transmissive and constructivist pedagogies indicates that, despite robust worldwide advocacy for inquiry-based methodologies, Greek curricula have not yet implemented these concepts in pre-service programs.

Taken together, the five analytical dimensions reveal a consistent structural pattern across the nine departments. Science education is characterized by

- partial implementation of officially listed courses,
- a narrow disciplinary profile dominated by physics and general science,
- a predominance of theoretical and lecture-based instruction,
- marginal institutional status through elective classification, and
- early front-loading within the first half of the study programs.

This constellation of features indicates that science education is positioned primarily as introductory background knowledge rather than as a core, developmental, and practice-oriented component of professional preparation. The convergence of these patterns across institutions suggests that the marginalization of science is not incidental but systemic.

DISCUSSION

The analysis of science education within DPEs uncovers structural and pedagogical tendencies that reflect ongoing global issues in teacher training. The five tables in the Results section collectively demonstrate a disjointed, inconsistent, and frequently peripheral placement of science within pre-service curricula. Analyzing these findings in the context of worldwide literature reveals systemic deficiencies and prospects for cohesive transformation.

A primary concern arising from **Table 1** is the disparity between the anticipated and executed courses. In numerous institutions, about one-third of the science courses listed in the study guides were not actually taught. This contradiction indicates that science education is susceptible to variations in administration, staffing, or enrollment. Comparable discrepancies between intended and implemented curricula have been documented in comparative analyses of teacher education in Europe and Latin America (Norambuena-Meléndez et al., 2023; Paz & Locatelli, 2023). This instability indicates the absence of robust institutional mechanisms to maintain curriculum fidelity and underscores the need for national coordination to establish and protect science standards within teacher preparation programs. At the same time, such discrepancies may also reflect broader structural constraints, including staffing limitations, fluctuations in student enrolment, and administrative factors that shape the viability of courses within autonomous university departments.

Table 2 highlights a disciplinary disparity that has considerable ramifications for teacher proficiency. The preeminence of physics, juxtaposed with the minimal representation of chemistry and biology, narrows the epistemic breadth of scientific education and risks sustaining a narrow perspective on scientific investigation. Modern curriculum theory posits that scientific literacy necessitates knowledge across various fields, including life, physical, and earth sciences, coupled with an understanding of the essence of scientific reasoning (Lederman et al., 2013; Roberts & Bybee, 2014). The present Greek framework markedly differs from foreign models that advocate for integrated or thematic methodologies in science education, connecting disciplinary knowledge to sustainability, technology, and quotidian phenomena. This divergence may be influenced not only by curricular choices but also by historical faculty composition, departmental traditions, and institutional resource allocation (Silva et al., 2023).

The pedagogical direction of the courses, as illustrated in **Table 3**, substantiates the assertion that Greek pre-service programs are mostly theoretical. Moreover, more than 50% of all courses are lecture-oriented, with less than 30% incorporating practical, experimental, or inquiry elements. This disparity reflects global research indicating that pre-service teachers' inadequate engagement in inquiry experiences diminishes their confidence in subsequently applying these methods in educational settings (Setiyani et al., 2025; Windschitl et al., 2012).

The predominance of lecture-oriented, content-focused science courses may be partially explained by the fact that many of these modules are taught by disciplinary scientists rather than specialists in science education, a pattern observed across several departments. While disciplinary expertise is essential, it does not necessarily entail pedagogical preparation in inquiry-oriented instruction, which may contribute to the persistence of transmissive approaches. This structural characteristic may contribute to the persistence of transmissive pedagogies and the limited integration of inquiry-based practices, as disciplinary expertise does not necessarily entail pedagogical training in inquiry-oriented instruction.

Constructivist and inquiry-based frameworks, fundamental to contemporary science education, necessitate active participation in scientific procedures, with experiments constituting a central mechanism through which learners construct meaning and develop scientific reasoning (Kotsis, 2024b). Moreover, controlled comparative research in primary classrooms has demonstrated that students who engage in real, hands-on physics experiments achieve significantly better conceptual understanding than those who rely exclusively on virtual simulations, underscoring the irreplaceable pedagogical value of authentic experimentation (Evangelou & Kotsis, 2019). Importantly, research on in-service primary teachers indicates that limited exposure to experimental practices during training is associated with hesitant or negative attitudes towards experimentation in physics teaching, which in turn constrains classroom implementation (Vlachos et al., 2024). The limited availability of these chances in Greek programs indicates a disparity between the professed commitment to inquiry-based pedagogy and its actual implementation in the curriculum.

The institutional positioning of science, as shown in **Table 4**, provides further evidence of marginalization. Approximately 25% of science-related courses are mandatory, while the balance is available as electives. This framework renders science education optional in numerous departments, allowing students to attain a teaching degree with limited engagement in scientific reasoning. Comparable configurations have faced international criticism for eroding teacher trust and sustaining science anxiety among generalist educators (Markwick & Reiss, 2024; Wang et al., 2015). When science is not regarded as an essential element of professional development, its symbolic and educational significance is diminished, influencing both teacher identity and subsequent classroom practices. However, such marginal positioning is also shaped by national credit frameworks, accreditation requirements, and competition with other core subjects within densely structured teacher education programs.

The chronological arrangement of courses outlined in **Table 5** exacerbates this issue. The aggregation of science courses within the initial two years of study, prior to practicum or methods courses, indicates a "front-loaded" curriculum that distinguishes disciplinary knowledge from its pedagogical implementation. Studies from Finland, Singapore, and Australia demonstrate that integrating scientific courses

throughout the curriculum and incorporating them into practical activities enhances PCK and fosters enduring engagement (Zhang et al., 2022). The Greek model, in contrast, reflects a more traditional structuring of teacher education in which disciplinary theory is largely separated from pedagogical application rather than developing in parallel with practice.

In addition to these quantitative discoveries, a qualitative study of course descriptions indicate the continued prevalence of traditional, content-focused pedagogies. The recurrent focus on presentation and summary diverges from global trends favoring problem-based and multidisciplinary learning. This conventional perspective may arise from the composition of faculty, where disciplinary scientists, rather than specialists in science education, frequently direct courses, or from institutional inertia in curricular reform. The prevalence of transmissive pedagogies restricts pre-service teachers' access to modern perspectives on learning and the essence of science.

Collectively, these data illustrate a fundamental disconnect between policy objectives for scientific literacy and the actual conditions of teacher training. Despite repeated emphasis by international organizations such as the European Commission (2020) and OECD (2023) on inquiry, interdisciplinarity, and sustainability as fundamental principles of science education, these priorities are only partially implemented in Greek teacher education. The data shown in **Table 1-Table 5** substantiates that the existing curricular framework appears insufficient to cultivate confident, inquiry-driven science educators who can effectively engage young learners in substantive exploration.

The mapping results indicate viable avenues for enhancement. The quantitative precision of the tables establishes a basis for data-informed reform: institutions may now identify existing gaps in disciplinary balance, course sequencing, pedagogical approaches, and structural status. Establishing national standards to mandate a certain number of obligatory, inquiry-based science courses over all four academic years might significantly improve coherence and fairness. Moreover, promoting collaboration between scientists and science education researchers could enhance disciplinary diversity and advance pedagogical innovation.

The trends observed in **Table 1-Table 5** illustrate overarching tensions in global teacher education: the conflict between academic autonomy and national coherence, the dichotomy between disciplinary depth and pedagogical relevance, and the contrast between theoretical instruction and inquiry-based engagement. Resolving these difficulties necessitates a collective view of science education as integral to the primary teaching mission, rather than an ancillary addition. Aligning the curriculum structure with this aim would advance Greek teacher education towards worldwide quality standards, while providing significant contributions to the global discourse on cultivating scientifically literate, critically thinking, and inquiry-driven educators.

IMPLICATIONS FOR POLICY AND PRACTICE

The results of this study have substantial significance for policymakers, curriculum developers, and higher education institutions aiming to improve the quality and coherence of science education in teacher preparation. The implications can be articulated at three interrelated levels:

- (a) national policy and regulatory frameworks,

- (b) institutional and departmental governance, and
- (c) program-level curriculum design and pedagogy.

While the Greek context exhibits specific institutional and historical circumstances, the systemic issues it uncovers, fragmentation, marginalization of science, and inadequate inquiry-based experiences, echo global apprehensions regarding the preparation of scientifically literate and pedagogically proficient primary educators. Addressing these difficulties necessitates synchronized adjustments across all levels: structural, curricular, and pedagogical.

At the national policy and regulatory level, the findings indicate the need for a national framework that establishes basic criteria for science education in teacher training. Presently, DPEs operate with considerable autonomy in curriculum development, resulting in significant discrepancies in course content and scope. This decentralization, although fostering academic independence, compromises national uniformity and comparability of teacher qualifications. Global evidence indicates that establishing a unified framework of essential competencies and outcomes for pre-service scientific education can ensure both equity and quality (European Commission, 2020; OECD, 2023). At the national level, recent efforts to redesign primary education science curricula in Greece explicitly emphasize coherence, an inquiry orientation, and alignment with contemporary scientific literacy goals, underscoring the urgent need for teacher education programs to be structurally aligned with these reforms (Kotsis et al., 2025). Frameworks such as the Australian professional standards for teachers and the European framework for the professional competence of educators delineate explicit expectations about teachers' scientific knowledge, pedagogical abilities, and attitudes toward inquiry and sustainability. Implementing a comparable paradigm in Greece could ensure consistency across institutions while allowing for contextual modification.

Furthermore, a regulatory framework must guarantee a minimum number of contact hours and mandate the inclusion of science education courses in teacher preparation programs. Longitudinal studies across multiple countries indicate that augmenting the proportion of mandatory science courses and integrating them throughout the degree program markedly enhances pre-service teachers' confidence, self-efficacy, and PCK (Markwick & Reiss, 2024; Wang et al., 2015). The elective status prevalent in several Greek curricula conveys an implicit notion that science is nonessential, a perspective that sustains inadequate involvement at the primary school level and perpetuates structural and psychological barriers to effective science teaching (Kotsis, 2024a). Policymakers could resolve this issue by mandating that all students in teacher education complete a core curriculum that includes essential scientific subjects, science pedagogy, and experiential inquiry opportunities.

At the program and curriculum design level, science education should strive for both vertical and horizontal integration. Science education should not be limited to initial semesters but should reemerge in increasingly sophisticated forms throughout the curriculum, culminating in practical teaching experiences associated with practicum or capstone projects. The spiral curriculum paradigm, which revisits topics and behaviors at progressively advanced levels, has demonstrated efficacy in promoting profound learning and transferability (Bruner, 1960; Zhang et al., 2022). Horizontal integration across disciplines should be encouraged through thematic or problem-based modules that connect science, technology, mathematics, environmental studies, and

social issues. Cross-curricular approaches are increasingly acknowledged as vital for equipping teachers to tackle the transdisciplinary aspects of real-world situations (Voogt & Roblin, 2012). Curricula must incorporate inquiry-based and experiential learning as an essential element of science teacher preparation. The research indicated a preponderance of theoretical, lecture-centric education with minimal laboratory or field experiences. Inquiry experiences are essential for cultivating instructors' scientific reasoning, curiosity, and confidence (Lederman et al., 2013). Universities might forge collaborations with schools, science centers, and environmental organizations to offer genuine inquiry contexts. The establishment of university-affiliated teaching laboratories for pre-service teacher experimentation, emulating effective models from Finland, the Netherlands, and Australia, could significantly improve the experiential aspect of teacher training (Beudels et al., 2022; Strat et al., 2024).

An additional impact pertains to faculty development and multidisciplinary collaboration. The efficacy of science teacher training relies on both the curriculum framework and the proficiency and pedagogical approach of the instructors. The investigation revealed discrepancies in instructor qualifications, with certain science courses being taught by educators from unrelated fields. Focused professional development and cooperative instruction between scientists and science education experts can reconcile disciplinary and pedagogical gaps. Joint appointments or co-teaching methods, effectively used in institutions in Canada and New Zealand, may be employed to enhance the integration of content and pedagogy (Strat et al., 2024).

Greek universities should use curriculum mapping and continual evaluation procedures at the institutional level. The current study illustrates how curriculum mapping can uncover concealed gaps and redundancies. Institutionalizing this process via annual internal audits that compare desired and delivered courses would enhance openness and facilitate development (Harden, 2001). Moreover, engaging external reviewers and stakeholders (such as educators, scientific education researchers, and government officials) helps ensure that curriculum revisions address changing educational and social demands.

In addition to structural reform, the findings carry significant implications for teacher professional identity and motivation. The devaluation of science in teacher school may lead to diminished self-efficacy among graduates, perpetuating a cycle of avoidance and fear around science instruction. Interventions that bolster teachers' feelings of ownership and leadership in science, such as peer mentoring, classroom-based research, or leadership roles in science outreach, have demonstrated efficacy in enhancing motivation and sustained engagement (Markwick & Reiss, 2024). It is important to acknowledge that implementing these reforms is not without challenges. Legislative frameworks, accreditation requirements, institutional autonomy, staffing availability, and resource constraints may limit the pace and scope of curricular change. In addition, existing departmental cultures and workload distributions can influence faculty's willingness and capacity to redesign courses or adopt inquiry-oriented pedagogies. Recognizing these constraints is essential, not to weaken the case for reform, but to emphasize the need for phased, collaborative, and context-sensitive approaches to curriculum development.

Ultimately, these ramifications pertain to the global community of scientific educators and politicians. The Greek situation highlights the need for a thorough international evaluation and comparison of teacher education curricula. International institutions such as UNESCO,

OECD, and ICASE could enhance their involvement in fostering collaborative benchmarking projects by generating comparative data on curriculum frameworks, pedagogical approaches, and learning outcomes in science education. Such projects will facilitate mutual learning across countries about innovations and challenges, advancing global progress towards a scientifically literate citizenry and sustainable development.

CONCLUSION

This study aimed to examine the organization and execution of science education in the curricula of DPEs and to contextualize these findings within a global framework of teacher education and curriculum development. The investigation disclosed a complex scenario: science education, while officially recognized as vital for the training of future educators, occupies a disjointed, inconsistently implemented, and frequently marginal role in Greek pre-service teacher training programs. The divergence between planned and implemented curricula, the disproportionate emphasis on physics, the prevalence of theoretical teaching, the optional nature of science courses, and their early positioning within degree frameworks collectively illustrate a system in which science education lacks coherence and systematic prioritization.

These findings align with global evidence indicating that science education in primary teacher training encounters similar structural challenges. In various nations, science typically contends for time and resources alongside literacy and mathematics, while pre-service teachers generally commence programs with insufficient confidence in science (Beudels et al., 2022). The Greek scenario illustrates how institutional autonomy, without a unified national policy, can result in disparities in science education and inconsistent graduate competencies. This fragmentation signifies an opportunity, as the data produced from this mapping process establishes a basis for evidence-based reform.

The study emphasizes the significance of curriculum coherence as the foundation of good teacher preparation. Coherence encompasses the alignment of learning outcomes, material, pedagogy, and assessment, as well as the gradual incorporation of scientific knowledge and inquiry techniques throughout the four-year teacher education program. Contemporary frameworks, including the next generation science standards and the European framework for key competences for lifelong learning, underscore that cultivating teachers' scientific literacy necessitates ongoing involvement with the essence and methodologies of science (European Commission, 2020; NGSS Lead States, 2013). Brief, fragmented, or exclusively theoretical courses are unlikely to develop the profound comprehension and assurance essential for prospective educators to promote inquiry-based learning in their classrooms.

The analysis highlights the essential importance of experiential and inquiry-based learning in pre-service programs. International research repeatedly indicates that inquiry experiences enhance teachers' capacity to design and execute investigative classroom practices (Setiyani et al., 2025; Strat et al., 2024), although the Greek curriculum analyzed offers limited opportunity for such experiences. Taken together, the findings underscore that the challenges facing science education in primary teacher preparation are not primarily pedagogical but structural in nature. Fragmentation, elective marginalization, and early front-

loading of science courses point to systemic patterns in curriculum design that constrain the development of coherent PCK and inquiry-oriented professional identity. This highlights the need to conceptualize reform not merely as the addition of courses or methods, but as a reconfiguration of curriculum architecture and epistemic priorities. Science education must be regarded as an essential element in the development of professional identity, transcending mere inclusion. Educators ought to graduate not merely as conveyors of knowledge but as enablers of curiosity, inquiry, and reasoning, attributes essential for democratic participation in scientific and technical advancements (Roberts & Bybee, 2014).

Subsequent investigations may advance this study in multiple avenues. Initially, comparative analyses across other national contexts can evaluate whether the characteristics observed in Greece, curricular fragmentation, elective status, and restricted inquiry practice, are similarly widespread in other regions, and which governmental mechanisms have been beneficial in mitigating these issues. Secondly, longitudinal studies tracking pre-service teachers into their initial careers could elucidate how curricular experiences influence classroom practices and student results in science. Third, mixed methods approaches that integrate curriculum analysis with interviews and classroom observations would enhance understanding of how instructors assimilate and implement their training. These investigations would expand the growing corpus of global research aimed at reconciling curriculum design with pedagogical implementation in science education (Strat et al., 2024).

The overarching implication of this research is to reassert the ethical and civic objectives of science education in teacher training. In a time marked by climate emergencies, digital evolution, and public discourse on evidence and misinformation, the role of educators transcends mere dissemination of scientific knowledge. They must develop in their students the ability to think, inquire, and act responsibly in a scientifically intricate environment. To do this, colleges and policymakers must guarantee that teacher education provides graduates with both knowledge and the pedagogical creativity and assurance necessary to render science significant and empowering for all learners. This study makes three interrelated contributions to the field of science education and teacher education research. Empirically, it provides the first comprehensive national mapping of the intended and implemented science education curricula across all DPEs, offering an evidence-based portrait of disciplinary balance, pedagogical orientation, and institutional positioning. Methodologically, it demonstrates the analytical value of curriculum mapping as a diagnostic tool for examining not only content coverage but also coherence, marginalization, and epistemic structure within teacher preparation programs. Theoretically, the findings advance the argument that the marginalization of science in primary teacher education is not simply a matter of individual confidence or instructional competence, but a structural consequence of curriculum architecture, institutional priorities, and knowledge hierarchies.

A further implication of the present findings concerns the inherent inertia that characterizes curricular change within DPEs. Although policy discourse and research evidence increasingly emphasize inquiry-based learning, interdisciplinarity, and scientific literacy, curricular reforms in university teacher education programs typically unfold slowly and incrementally. In practice, substantial curriculum revisions often require several years to be designed, approved, and implemented,

frequently spanning a full review cycle of approximately four to five years. This temporal lag means that misalignments between contemporary curricular goals and existing program structures may persist for extended periods, even when the need for reform is widely recognized. Acknowledging this structural inertia is important for setting realistic expectations about the pace of change and for interpreting the present findings not as static deficiencies, but as indicators of systemic constraints within higher education governance. By foregrounding these structural dimensions, the study contributes to international debates on curriculum coherence, scientific literacy, and the professional formation of primary teachers.

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